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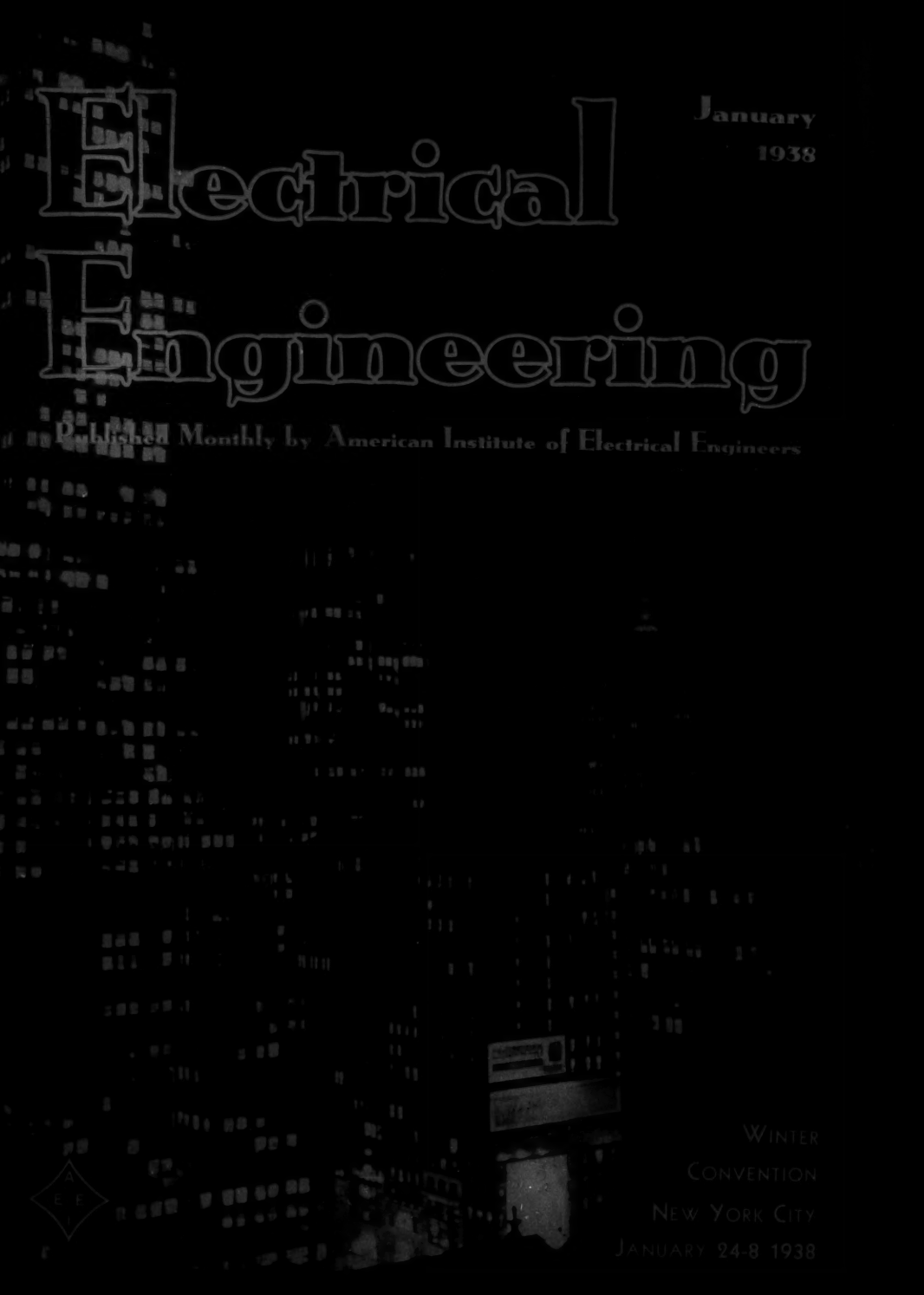

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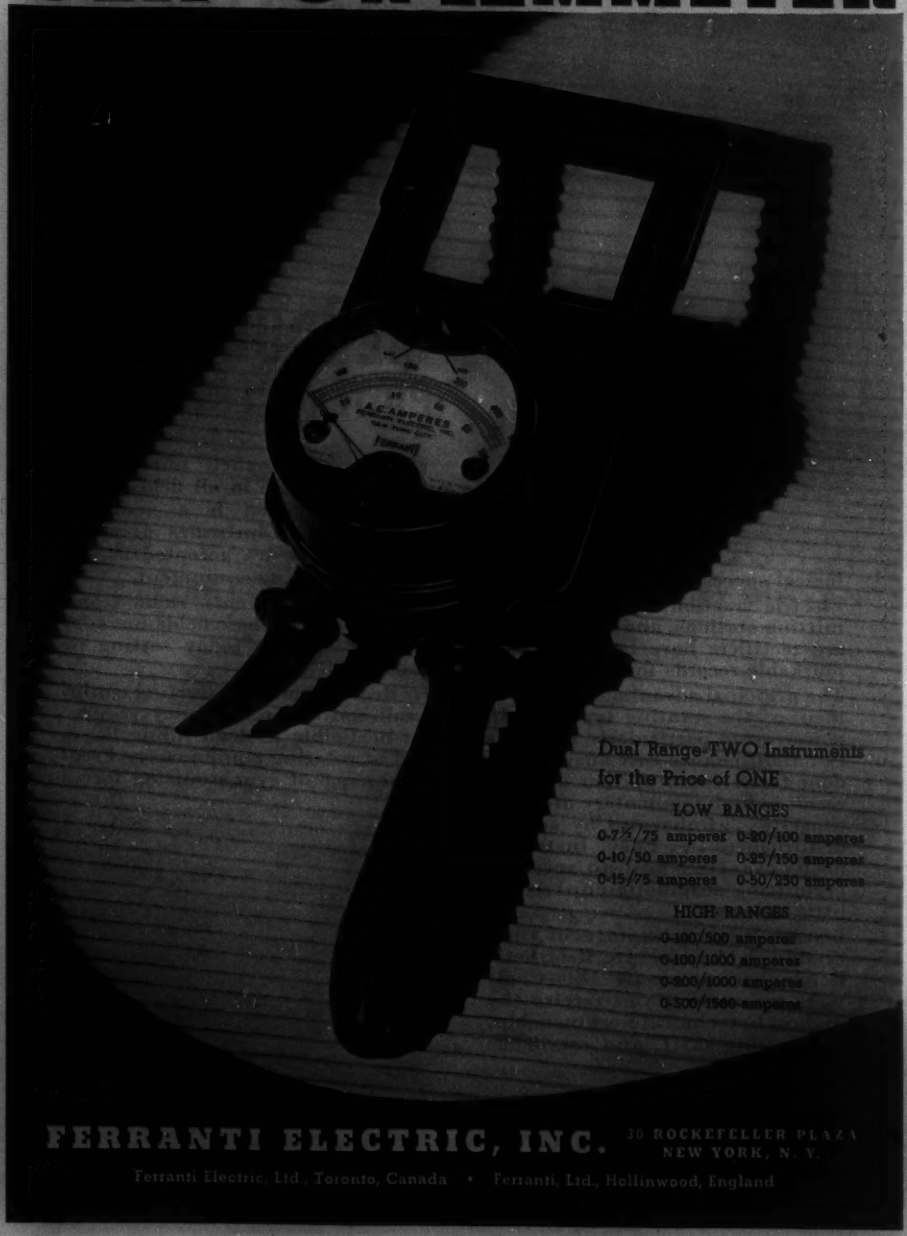

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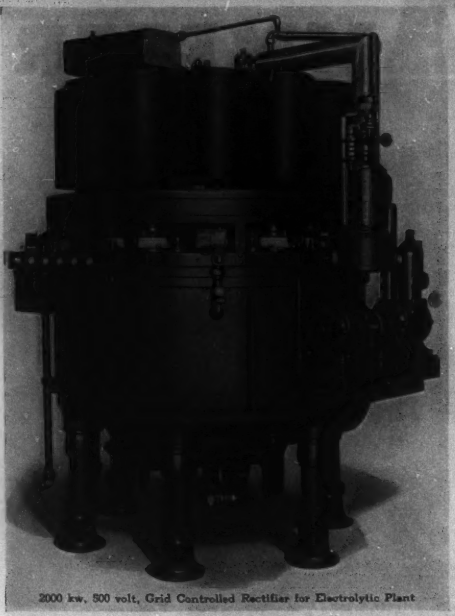

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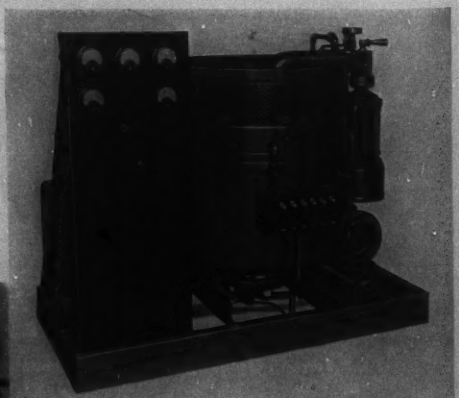

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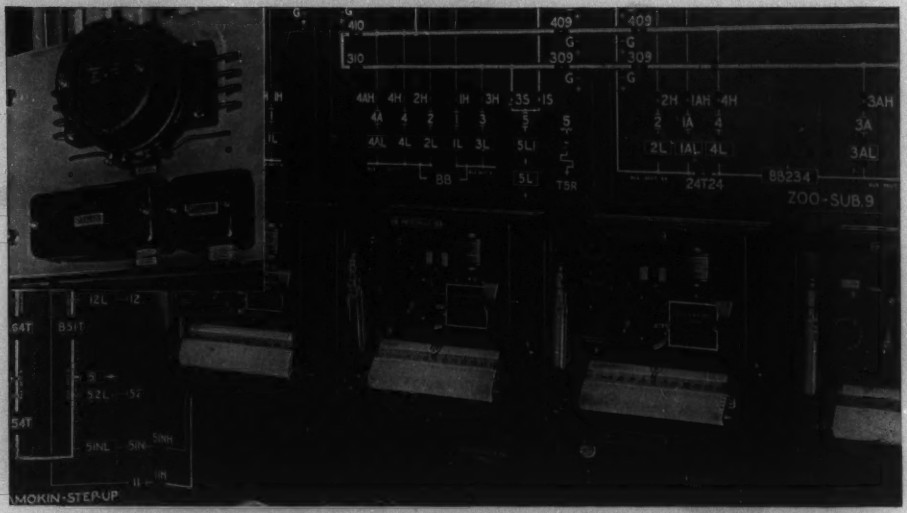

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The Cover

Night view looking northeast from the roof of the Engineering Societies Building in New York City, headquarters for the Institute's forthcoming winter convention

Photo by Floyd A. Lewis (A'31, M'35)

High Lights

New Publication Procedure. This is the first issue of ELECTRICAL ENGINEERING to be published in accordance with the new developments in publication policy announced in the November 1937 issue, page 1409. Under the new provisions, this and succeeding issues will consist of two principal parts. For example, in this issue the first 48 pages contain articles of general interest and news of Institute and related activities, and the following section of 60 pages contains papers preprinted from the 1938 volume of the TRANSACTIONS. Following a necessary transition period, all discussions published will be correlated with their respective papers. Another feature of the new plan is the provision of "advance copies" of papers approved by the technical program committee for presentation at national conventions and District meetings; an order form is included in the advertising section of this issue.

Electric Passenger Vehicles. The past few years have brought about great changes in vehicles and equipment for public surface transit in urban centers. Development of the Presidents' Conference Committee street car, new and greatly improved trolley coaches, and gas- and Diesel-electric busses and the introduction of the "all-service" vehicle have brought about marked changes and improvements in electric propulsion equipment (*Transactions pages 50–6*). Economically, electric trolley coaches are not adaptable to public transportation in all urban centers, for each city has its own peculiar transportation problems. Some of the economic and operating features of electric trolley coaches have been outlined, with the aim of indicating the type of community in which the electric vehicle is most suitable (*Transactions pages 57–60*).

Winter Convention. At the "general" session of the AIEE 1938 winter convention, which will be held in New York, N. Y., January 24–28, a noted economist will speak on a subject of importance to engineers (*page 36*). Other winter-convention attractions announced in this issue include: presentation of the 1937 Edison Medal to a past-president of the Institute; the annual smoker and dinner-dance; an interesting variety of inspection trips; and a post-convention cruise to Bermuda. Changes have been made in five technical sessions, and programs of several technical conferences have been announced (*pages 33–5*).

Correlation of Sphere-Gap Data. Sphere gaps, although widely used for measuring high voltages, are not absolute standards; consequently, any improvement in the measurement of spark-over voltages by means of the sphere gap must come from frequent correlations of data obtained by independent observers. A new correlation presents spark-over curves for spacing-to-diameter ratio; suggestions for a spark-over voltage chart covering the entire useful range of sphere sizes, spacings, and air densities; and new air-density correction factors (*Transactions pages 45–9*).

Tensor Analysis. A new game, called "hunting the tensor" is introduced for the first time in this issue. This game has been designed with the specific intent of disturbing the electrical engineer's latent curiosity about the reputably abstruse subject of tensor analysis. The hunt consists of three parts. The tensor specimen is caught in this issue, but the mounting and cataloguing of the specimen must remain for a subsequent installment (*pages 3–9*).

Thyratron Motors. The search for a simple variable-speed a-c motor has extended over many years, yet no generally known device has been thoroughly satisfactory. Many types of a-c drive are in use today and many more have been designed and discarded or never applied. The thyratron motor, devised within the last few years, or some similar electronic device, may provide the ultimate solution to the problem (*Transactions pages 19–24*).

Studies of Living Tissue. An extension of a previous paper on electrical studies of living tissue shows that human and frog tissues behave electrically as a simple circuit consisting of one capacitor and one or more resistors. The correlation between tissue response and the voltage distribution in live tissue has been determined and is described on the basis of the voltage distribution in the equivalent circuit (*Transactions pages 1–4*).

Carrier-Pilot Relay System. A paper in this issue outlines some of the reasons for the use of pilot-relay equipment and describes a new high-speed distance type of carrier-pilot relay system in which the desirable high-speed and back-up characteristics of the step type of distance protection are combined with the simultaneous tripping characteristics of a pilot circuit (*Transactions pages 5–10*).

Corona Voltages in Transformers. In insulation tests of oil-immersed transformers, insulation deterioration has been found to be caused by corona or local discharges in the oil and over solid insulation surfaces. Results of a series of tests show that the impulse voltage at which corona appears is about 2.2 times the 60-cycle voltage at which it appears (*Transactions pages 34–6*).

Prizes for Papers. AIEE national and District prizes for initial and Branch papers to be awarded during 1938, will be accompanied by cash awards (*page 37*).

Resistance Welding. A subcommittee report describes some of the recent advances in controlling time, pressure, and current in resistance-welding processes and some of the improvements in welding apparatus. Electric-welding engineers are attempting to establish quantitative, scientific methods of resistance welding, instead of the outmoded rule-of-thumb methods (*Transactions pages 37–8*).

Petersen Coils. Until recently, Petersen coils, although widely used in Europe in protective grounding practice, have been little used in the United States. Electric service may be improved by the use of properly designed and applied Petersen coils (*Transactions pages 11–18*).

Carrier Telephone System. In a new single-channel carrier telephone system, opposite sidebands of the same carrier frequency are used for opposite directions of transmission. The upper sideband is used in one direction and the lower sideband in the other, the carrier being suppressed (*Transactions pages 25–33*).

Temperature Limits. Oil-immersed neutral-grounding transformers and reactors should not exceed safe temperature limits during faults that may last for several minutes; temperatures for various fault durations that will produce the same aging of insulation as is produced by the present standard of 160 degrees centigrade for a fault period of one minute may be found by calculation (*Transactions pages 39–44*).

Electrons. Devices depending for their operation upon those small negative particles called electrons constantly are increasing in number. What the electron is, how it constitutes electricity, and how it may be used are told in a simple way in an article intended to aid those who may not be familiar with recent theories in this subject (*pages 26–32*).

Interconnected Systems. An engineer widely recognized as an authority on interconnection problems describes in this issue some typical operating and economic advantages of interconnection, based upon experience with a co-ordinated system extending over a large area east of the Mississippi River (*pages 16–25*).

Electrified Railroad System. Design and operating details of the extension of the Pennsylvania Railroad's electrified system to Harrisburg, Pa., now nearing completion, are described in an article in this issue (*pages 10–15*).

Letters to the Editor. Discussions of the following topics are included in this month's "Letters" section: registration of engineers, tensor analysis, capacitor motors, and graphical solution of impedances (*pages 41–3*).

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). ¶ Copyright 1938 by the American Institute of Electrical Engineers. Number of copies this issue—21,800.

What Is Tensor Analysis?

By BANESH HOFFMANN

Although a powerful analytical engineering tool, tensor analysis has been supposed by many to be an abstract toy used only by the mathematician and the theoretical physicist. This article, written by a mathematician, is intended to present the rudiments of the subject, and to point the way toward further study and a working knowledge of tensors in engineering. Readers who feel that mathematical subjects cannot be exposed in an entertaining—or even amusing—fashion may find in this article something of a surprise.

THE TENSOR'S reputation for performing prodigious feats in the more intricate realms of mathematics and physics unfortunately has given to many the impression that the understanding of tensor analysis is within the powers of only a few highly trained specialists.

Actually there is very little difficulty in tensor analysis, and its main ideas can be easily understood by anyone who has been able to grasp the essentials of, say, the differential calculus. The greatest difficulty in the study of the tensor calculus is the feeling of hopelessness its remarkable reputation inspires in the would-be student; and once this feeling is overcome the tensor stands revealed as a quite simple concept, which has in fact often been seen before, in various guises, in elementary mathematics.

True, the tensor is a being of considerable power. But it has been so thoroughly trained by the world's greatest trainers of unruly invariants that it is rapidly becoming a favorite domestic pet of infant mathematicians, and what I want to do in this article is to tell enough about its habits so that the reader will begin to feel a warm friendship toward it. No attempt is made to be mathematically complete; there is no space for that here. Nor is this article to be regarded in any sense as a textbook on elementary tensor analysis. Instead, it should be viewed as a supplement to existing textbooks on the subject, and as a general survey and sight-seeing tour of the ground they cover so much more adequately.

This article falls naturally into three parts. The first treats the fundamental ideas of tensor analysis so far as algebraic properties are concerned. This will serve to bring out the essential nature of the tensor and will pave the way for the second part, in which differential properties of the tensor are discussed. The third part is concerned with some of the applications of tensor analysis in mathematics and physics and illustrates the less specific discussion of the first two parts.

Equations are numbered so as to indicate the part to which they belong. Thus equations 1.9 and 1.13 belong to part I, with 1.13 later than 1.9, while equations 2.3 and 3.5 belong, respectively, to parts II and II.

Part I—Algebraic Properties

We are going to indulge in that well-known, and justly famous, indoor sport of hunting the tensor. We want to do this as simply as possible, but the one-dimensional tensor looks rather stupid when caught and bears no superficial resemblance whatever to its multidimensional relatives—think of a one-dimensional vector, for instance—so we must hold our hunt in two dimensions.

What shall be our hunting ground? Well, consider two points P, Q in a plane, their Cartesian co-ordinates being (x, y) and $(x + dx, y + dy)$ respectively. Their distance apart, which we call ds, is given by the well-known Pythagorean formula

$$(ds)^2 = (dx)^2 + (dy)^2 \tag{1.1}$$

Lurking in this apparently guileless equation are as many as four different varieties of tensor; a scalar, a vector, a second-rank tensor, and another vector of a type different from the first. Can there be any question that this is going to be our hunting ground?

We must not expect the hunt to be easy, for the more elaborate tensors are masters of the art of concealment and have developed a system of protective coloring of such efficacy that it enabled them to remain hidden from the searching eyes of mathematicians for centuries. So difficult are they to see, indeed, that once they have been caught it is often necessary to fasten an indelible label on their backs or they will vanish from sight again. We shall have occasion to use this technique during the present hunt.

Since we know so very little about tensors as yet, I shall bring along some reference books and we shall call a halt whenever we are in doubt, to find out what information they have to help us.

The essence of all detection being method, let us be systematic. Our first step is to label everything in sight with great care, and in such a way that we can file away all our data in an immediately accessible manner. Accordingly, we methodically give to the co-ordinates x, y the numbers 1, 2. But to remind ourselves that they are still co-ordinates we also use an x. Thus

$$x \to x^1, \quad y \to x^2 \tag{1.2}$$

Written especially for ELECTRICAL ENGINEERING, this is the first of three parts of an article presented because of the widespread interest in the subject among Institute members. Parts II and III will appear in an early issue. ALL RIGHTS RESERVED BY THE AUTHOR.

BANESH HOFFMANN is an instructor in mathematics at Queens College, Flushing, N. Y. Doctor Hoffmann was born in England in 1906. After receiving his early education at St. Paul's School, London, he studied mathematics at Oxford University, graduating in 1929 with first-class honors. He then came to the United States to be assistant to Professor O. Veblen at Princeton University, where he subsequently received the degree of doctor of philosophy. Following a period as research associate at the University of Rochester, he returned to Princeton as a member of the Institute for Advanced Study to work with Einstein, Infeld, and Veblen. Doctor Hoffmann is the author of more than 20 research papers, mainly in the field of relativity theory. In recent years he has presented papers on tensor analysis at several AIEE meetings.

Is this too pedantic? After all, we must look ahead, and what could we do in a couple of hundred thousand dimensions? We couldn't give different letters to the different co-ordinates and there seems no way of avoiding the idea of numbering them instead. In n dimensions the co-ordinates are denoted by $x^1, x^2, \ldots, x^n$.

As to filing away our data, we certainly must put all the co-ordinates in the same folder. We label the folder x^a and put into it x^1 and x^2; in n dimensions, $x^1, x^2, \ldots, x^n$.

Forget about this n-dimensional business for the present. When we have found out all about two-dimensional tensors we have only to say, "Presto! $a, b, \ldots$ to go from 1 to n instead of from 1 to 2," and we shall at once find ourselves in n dimensions.

So far, then, we have the notation

$$x^a = (x^1, x^2) = (x, y) \tag{1.3}$$

implying also

$$dx^a = (dx^1, dx^2) = (dx, dy) \tag{1.4}$$

The almost continual mention of co-ordinate systems in reference books shows that they must be very intimately related to our problem. We had better investigate them. In this part we shall be concerned only with co-ordinate systems in which the co-ordinate lines are straight. The most general transformation of co-ordinates which preserves their straightness is of the form

$$\bar{x} = px + qy, \bar{y} = rx + sy \tag{1.5}$$

where $(\bar{x}, \bar{y})$ are the new co-ordinates and p, q, r, s are constants.

The notation given in equation 1.3 does not seem to offer any advantage. But let us extend the idea a little. Let us put all the constants p, q, r, s into the same folder and label it C^a_b, where the suffixes a, b range over 1, 2 independently and

$$\begin{array}{c|c} C^1_1 & C^1_2 \\ \hline C^2_1 & C^2_2 \end{array} = \begin{array}{c|c} p & q \\ \hline r & s \end{array} \tag{1.6}$$

We can now write equation 1.5 compactly in the form

$$\bar{x}^a = \sum_{b=1,2} C^a_b \, x^b \tag{1.7}$$

Long association with such obedient slaves as tensors produces extraordinary exhibitions of laziness; and Einstein, noting that a summation sign occurred only when a suffix appeared twice, decided to omit the summation signs entirely and make the convention that repeated suffixes are automatically to be summed over their whole range of values. This is called the *summation convention** and allows us to write equation 1.7 in the form

$$\bar{x}^a = C^a_b \, x^b \tag{1.8}$$

We shall use this convention consistently throughout.

Let us fortify ourselves by finding the definition of a tensor, and then we can start out on the hunt. The definition is somewhat shocking. It seems to consist entirely of abstract nonsense. But let us note a slightly simplified version for the present and see if we cannot understand it better after we have caught a few representative tensors and studied their habits at first hand. The definition makes use of the notion of an inverse transformation and we must look at this before we can talk about tensors in general.

Suppose that we transform from co-ordinates x^a to co-ordinates $\bar{x}^a$ by means of equation 1.8 and from $\bar{x}^a$ to $\bar{\bar{x}}^a$ by means of

$$\bar{\bar{x}}^a = c^a_b \, x^b \tag{1.9}$$

Then if, when we get to the co-ordinates $\bar{\bar{x}}^a$, we find ourselves back in the co-ordinate system from which we started, namely x^a, we call transformation 1.9 the *inverse* of transformation 1.8. If we work out the relationship between $\bar{\bar{x}}^a$ and x^a obtained from equations 1.8 and 1.9 we find

$$\bar{\bar{x}}^a = C^a_b \, c^b_c \, x^c \tag{1.10}$$

which the reader can verify for himself by writing the various equations in full. Remember the summation convention applies twice in equation 1.10. If equations 1.8 and 1.9 are inverse transformations,

$$\bar{\bar{x}}^a = x^a$$

which may be written

$$\bar{\bar{x}}^a = \delta^a_c \, x^c \tag{1.11}$$

where

$$\delta^a_c = \begin{array}{c|c} \delta^1_1 & \delta^1_2 \\ \hline \delta^2_1 & \delta^2_2 \end{array} = \begin{array}{c|c} 1 & 0 \\ \hline 0 & 1 \end{array} \tag{1.12}$$

So the condition that equations 1.8 and 1.9 be inverse is that

$$c^a_b \, C^b_c = \delta^a_c \tag{1.13}$$

If the reader will write all these equations in full he will see exactly what they signify and will also obtain a clear idea of the useful habit of the quantity δ^a_c of changing suffixes, as $x^a = \delta^a_c \, x^c$. Since δ^a_c is always turning up and doing useful work it has earned the title *Kronecker delta*, in honor of the famous mathematician Kronecker, who apparently did not invent it.

We can now look at the definition of a tensor, but for goodness sake let us not try to understand it just yet. We shall merely store it away for reference. According to our textbooks a tensor seems to be something or other having 2^r components in each co-ordinate system —n^r in n dimensions. Here r is some integer, 0,1,2,3,..., depending on the type of tensor. If these components are denoted by the symbol $T^{ab\ldots}_{cd\ldots}$, the dots denoting further suffixes, then whenever the co-ordinates transform according to equation 1.8 the components of the tensor transform according to the law

$$\bar{T}^{pq\ldots}_{rs\ldots} = T^{ab\ldots}_{cd\ldots} \, C^p_a \, C^q_b \ldots \, c^c_r \, c^d_s \ldots \tag{1.14}$$

Starting the Hunt for the Tensor

We start the hunt by looking for the scalar in equation 1.1. This happens to be very easy. The reference books point out that a scalar is merely a tensor with no suffixes and thus with only one component in each co-ordinate

* For us to call it an exhibition of laziness is like the pot calling the kettle black. Do we not ourselves habitually omit the usual × sign for multiplication?

system. What is its law of transformation? If we study equation 1.14 carefully we see that a scalar must transform according to the law

$$\bar{T} = T \tag{1.15}$$

This looks trivial, but consider how important such an entity is in everyday life. We see that a scalar is something which can be measured by one number and which has the same value for every co-ordinate system. Practically everything we can think of in mathematics and physics seems to be a scalar; for example, the number of vertices of a geometrical figure, the sum of its angles, the length of a line, the magnitude of a force, the volume of a lump of rock. We are almost tempted to think that everything is expressible by means of scalars, but we shall later find many things that are not scalars.

Where is the scalar in equation 1.1? Obviously it is ds, since this quantity is the length of the line PQ and, however much we fool around with the co-ordinate system, the actual points P and Q, and therefore also the value of ds, will not change.

That was simple. But before we start looking for the vector let us remark that if the left hand side of equation 1.1 is a scalar, the right hand side must be too. This is going to be of real interest later.

Now for the vector. The reference books all seem to agree that a vector is a tensor with only one suffix. That is all very well, but we happen to know a vector is nothing of the sort. It is something having magnitude and direction. Why do the books try to confuse us by using the word in a different sense?

The books all say the same thing. Perhaps there is some sense to it after all. Certainly the definition of a vector as something having magnitude and direction

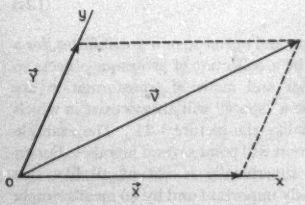


Figure 1. Sketch demonstrating the parallelogram law of addition as applied to vectors

cannot be entirely correct. It includes an extraordinary assortment of miscellaneous objects which are anything but vectors; for example, archers' arrows, compass needles and even, with a little stretching, symphony orchestras!

What is it, then, that distinguishes between genuine vectors and flag poles, stars, and similar objects undoubtedly having magnitude and direction? It is the parallelogram law of addition. Two genuine vectors $\boldsymbol{X}$, $\boldsymbol{Y}$ may be added to form the vector $\boldsymbol{V}$ as shown in figure 1. Evidently archers' arrows, flag poles, and similar things do not behave in this way. They are therefore not vectors.

This vector law of addition is important. It shows that vectors have components. For the vector $\boldsymbol{V}$ can be replaced by the sum of the vectors $\boldsymbol{X}$, $\boldsymbol{Y}$, and the magnitudes of the latter are what we call the components of $\boldsymbol{V}$ along the directions Ox, Oy. Whatever the co-ordinates, we can always find corresponding components for $\boldsymbol{V}$ and there is only one set of components per co-ordinate system.

More, we can find from the parallelogram law exactly how these components change as the co-ordinates are altered. If the co-ordinates undergo the transformation indicated in equation 1.8 the components V^a of $\boldsymbol{V}$ undergo the transformation

$$\bar{V}^a = C^a_b V^b \tag{1.16}$$

This is precisely the law we get from equation 1.14 for an entity T^a. So apparently the books were right after all. We are beginning to have a real respect for the definition of a tensor. We have already seen that it includes such very useful objects as scalars and vectors, and we begin to have confidence that with perseverance we shall find even more treasures hidden within it.

We shall not pause here to discuss such an entity as T_a which, having but one suffix, is also, presumably, a vector; but there are certain somewhat philosophical points about tensors in general which we can discuss with our present knowledge of vectors.

Why, for example, do we bother with components? That a vector has components is true. But components are such shifty, characterless things, always changing their attitude to comply with the dictates of co-ordinate transformations, while the vector itself is steadfast and unwavering, displaying a fine scorn for changes in mere co-ordinates. Would it not be simpler to deal directly with the vector instead of its ever-changing components? Unfortunately not! The powerful methods of mathematical analysis cannot be applied directly to the vector, but they are immediately applicable to its components. So whenever our problems become even slightly intricate we are forced to deal with vectors in terms of their components. This is why an understanding of how they change under co-ordinate transformations is so important. So frequent is the use of components in practice that, as we have seen in equation 1.14, we ultimately think of vectors as sets of components with definite transformation properties instead of as directed magnitudes adding in a certain way.

Yet there is something curious about this situation, for the components evidently must behave so as to reflect all the properties of their parent vector; and the parent vector's most characteristic property is its ability to exist without co-ordinates! The resolution of this paradox is important for the entire study of tensor analysis, and fortunately a compromise is possible. For we are not really interested in individual tensors; only in relations between them. For instance, though the scalar ds undoubtedly exists, it becomes of mathematical interest only when we can say what its value is and this ultimately implies a comparison with the standard yard, another scalar. Again, the momentum of a body becomes of interest when we can say something about it, and the law of conservation of momentum, for example, deals

with a comparison of momenta at different times. Any linear relation between vectors, such as

$$U - 5V = 8W \tag{1.17}$$

always can be written in the form

$$R \equiv (U - 5V - 8W) = 0 \tag{1.18}$$

so that our main interest turns out to be the vector zero!* It is evident from the parallelogram law that the components of the vector zero are themselves zero, this being true whatever the co-ordinate system. Thus for a zero vector the co-ordinate system has no influence at all on the values of its components and so if the equations

$$R^a = 0 \text{ (that is, } R^1 = 0, R^2 = 0) \tag{1.19}$$

are true in a single co-ordinate system they are true in every one. This is all we may reasonably expect from the components in their effort to emulate the aloofness of the parent vector. But we never need to use more than this for we can actually write equation 1.18 in terms of components as

$$R^a \equiv U^a - 5V^a - 8W^a = 0 \tag{1.20}$$

or as

$$U^a - 5V^a = 8W^a \tag{1.21}$$

which shows that any vector equation of the type of equation 1.17 immediately can be put into component form, and that if the component equations are true in one co-ordinate system they are true in all, and actually imply the validity of the original vector equation. For this reason we no longer bother to write down the original vector equation but regard the component equations as entirely equivalent to it. The law of transformation expressed in equation 1.16 for vectors is the counter part of the parallelogram law of addition and exhibits the essential properties needed for our argument. For, if the components V^a are zero, equation 1.16 shows that the components $\overline{V}^a$ in *any* other co-ordinate system will vanish also.

Figure 2. Segmented line representing voltage across the voltage coil of a wattmeter. The direction denotes the phase, and the scale the magnitude, of the voltage

The law of transformation 1.14 for tensors is of a very rare sort, giving to tensors all the properties we have just found for vectors. For example, any tensor equation can be put in the form

$$T^{ab\ldots}_{cd\ldots} = 0 \tag{1.22}$$

and this, if true in one co-ordinate system, is true in all, thus being as independent of co-ordinate systems as anything with components ever can be. Also, equation 1.14 ensures that a tensor has only one set of components per co-ordinate system. For if we start with some co-ordinate system, I; transform to another, II; from this to III; and so on in a circle till we come back to I, the tensor components also follow a circle, reaching their original values when we get back to I. Only the tensor law of transformation, and slight generalizations associated with relative tensors, have all these properties.

* Whittaker has described all of mathematics as variations on the theme 0 = 0.

The Tensor Discovered

Back to the hunt! The vector in equation 1.1 is hardly trying to conceal itself. It is (dx, dy), or in the new notation, dx^a. The proof? Well, it has two components per co-ordinate system and we have only to see how they transform. If the co-ordinates are transformed in accordance with equation 1.8 we have

$$\overline{x}^a = C^a_b\, x^b, \qquad (\overline{x}^a + d\overline{x}^a) = C^a_b\,(x^b + dx^b)$$

and, by subtraction, as is easily seen if the equations are written in full,

$$d\overline{x}^a = C^a_b dx^b \tag{1.23}$$

which is precisely the law of transformation expressed in equation 1.16. Therefore dx^a is a vector.

That was almost as easy as finding the scalar, but the rest is not so simple. Before we look for the second-rank tensor in equation 1.1 let us make yet another remark about vectors, also applicable in principle to any type of tensor.

We tested the claim of dx^a to be a vector by counting its components and seeing how they transformed. This point of view frees us from the impulse to look for something like

(1.24)

when seeking a vector, and opens up new possibilities, for a vector can actually be a collection of grotesque objects so long as their number and mode of transformation are correct, in which case a "space" will always exist in which the vector does look like the picture 1.24. The example of an alternating current will point several morals. For an alternating current superficially is not at all like this picture. An extremely important and by no means simple discovery was that it could in fact be represented as a vector, and even so the "space" in which it exists really has one axis time.

However, we can also represent this vector in other "spaces." For the sake of argument, let us imagine we do not know that an alternating current is a vector. We can devise an experimental method for discovering that it is a vector by using a special ammeter, such as is used in some a-c calculating boards. This instrument really is a dynamometer wattmeter with an arbitrary voltage on one coil and the alternating current in the other. We adjust the voltage on the voltage coil to some definite phase and some definite amount by twisting two knobs, and such an adjustment can be represented conveniently by means of a segmented line Ox^1 as shown in figure 2, the direction denoting the phase and the scale the magni-

tude of the voltage. With this setting Ox^1 let us assume that the meter reads V^1. Repeating the experiment for a new setting, Ox^2 we shall obtain a second meter reading V^2. We may look on such pairs of settings Ox^1, Ox^2 as co-ordinate axes in some "space" as indicated in figure 3, this sort of trickery being standard practice in mathematics. Suppose now that, instead of the pair of settings Ox^1, Ox^2, we take new ones $O\bar{x}^1$, $O\bar{x}^2$. The most general relation possible between Ox^1, Ox^2 and $O\bar{x}^1$, $O\bar{x}^2$ can be represented by precisely the formula 1.8 and we may therefore regard the use of different settings as a change of axes. Naturally, the new meter readings $\bar{V}^1$, $\bar{V}^2$ will differ from the old, and if the instrument is correctly adjusted, they will be related to the old readings by the formula 1.16. It follows from this that (V^1, V^2), or V^a, are the components of a vector!

Notice how this vector has shown itself. Not as a mathematical representation of $I\sin(\omega t+\theta)$ in a space having one axis time, but as a directly measured entity which can be represented in the manner of 1.24 if we invent a space whose co-ordinate axes are lines of the type Ox^1, Ox^2; whose co-ordinate axes are really nothing but the way we twisted the knobs of the instrument to adjust the phase and magnitude of the voltage! Had we looked directly for anything resembling 1.24 here we hardly could have been successful.

Be careful not to confuse this sort of vector with the sort found by Kron [*EE, Nov. 1936, p. 1220–42*]; those vectors and tensors belong to still other types of spaces.

So much for vectors for the present. Now for the second-rank tensor in equation 1.1: It is hiding with well-nigh perfect mimicry and we shall have to prod it

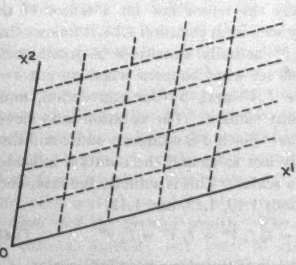


Figure 3. Co-ordinate axes formed by a series of hypothetical wattmeter readings arranged in a mathematical "space"

into showing itself by pulling on the co-ordinate system, keeping our eyes open for suspicious reactions.

We have already had occasion to remark that the right-hand side of equation 1.1,

$$(dx^1)^2 + (dx^2)^2 \qquad (1.25)$$

must be a scalar. Let us test this.

We try a translation to a new origin:

$$\bar{x}^a = x^a + q^a \qquad (q^a \text{ constants}) \qquad (1.26)$$

This gives

$$d\bar{x}^a = dx^a$$

and evidently

$$(dx^1)^2 + (dx^2)^2 = (d\bar{x}^1)^2 + (d\bar{x}^2)^2 \qquad (1.27)$$

Nothing suspicious there. Try a rotation through an angle θ:

$$\bar{x}^1 = x^1\cos\theta + x^2\sin\theta, \qquad \bar{x}^2 = -x^1\sin\theta + x^2\cos\theta \qquad (1.28)$$

If we work it out, we find, once more, that

$$(dx^1)^2 + (dx^2)^2 = (d\bar{x}^1)^2 + (d\bar{x}^2)^2$$

Even if we try a combination of translation and rotation we still get this result. Perhaps there is nothing to look for after all. Let us try one more transformation before we give up; this time a rotation through such an angle that PQ is parallel to the $\bar{x}^1$-axis. Then the $\bar{x}^2$ co-ordinates of P and Q are equal and so $d\bar{x}^2$ will vanish. Thus, instead of equation 1.27, we shall now have

$$(dx^1)^2 + (dx^2)^2 = (d\bar{x}^1)^2 \qquad (1.29)$$

No longer a sum of squares of co-ordinate differences! A clew at last! If we follow the trail we are sure to find the tensor.

But I hear you object that it *is* a sum of squares and that, by accident, one of them happens to be zero; that it is only laziness which makes mathematicians leave out terms which happen to be zero.

Yes. I have to admit it. But the whole thing was only a trap and had nothing directly to do with the tensor we are after. I did it to force you into your present attitude of insisting that I recognize the existence of a quantity even though it happens to be zero. And now I am going to feel entirely at liberty to make you recognize the existence, not only of *two* quantities which have been pretending to be zero, but also of two other quantities which have been pretending to be unity—another symbol which mathematicians like to omit!

Make a transformation which stretches the x^1-axis but not the x^2-axis:

$$\bar{x}^1 = kx^1, \ \bar{x}^2 = x^2 \qquad (k \text{ a constant}) \qquad (1.30)$$

Here we find

$$(dx^1)^2 + (dx^2)^2 = (1/k^2)(d\bar{x}^1)^2 + (d\bar{x}^2)^2 \qquad (1.31)$$

and, genuinely, we no longer have the sum of squares of co-ordinate differences on the right. This can only mean that the notion that the square of the distance between two points is equal to the sum of the squares of their co-ordinate differences must be incorrect. Admittedly it is correct in Cartesian co-ordinates numbered in inches, but for more general co-ordinates it evidently is not so, and I now ask you to recognize that the $(dx^1)^2$ term on the left of equation 1.31 in reality is some number times $(dx^1)^2$ but that the number happens by chance to be unity. I shall label it g_{11} and write, instead of equation 1.1,

$$(ds)^2 = g_{11}(dx^1)^2 + (dx^2)^2 \qquad (1.32)$$

Although in Cartesian co-ordinates g_{11} is unity so that we don't notice it, on the right of equation 1.31 it is clearly visible as $1/k^2$ and affords our first real glimpse of the second-rank tensor in equation 1.1.

By stretching the x^2-axis instead of the x^1-axis as before, we shall bring to light the existence of another quantity masquerading as unity, this time multiplying

$(dx^2)^2$. We label this new quantity g_{12} and revise equation 1.32 to read

$$(ds)^2 = g_{11}(dx^1)^2 + g_{22}(dx^2)^2 \tag{1.33}$$

What next? Let us see what happens when we change the angle between the axes. A simple transformation that does this, among other things, is:

$$\bar{x}^1 = x^1, \bar{x}^2 = x^1 + x^2 \tag{1.34}$$

This gives $dx^1 = d\bar{x}^1$, $dx^2 = d\bar{x}^2 - d\bar{x}^1$ so that

$$(dx^1)^2 + (dx^2)^2 = 2(d\bar{x}^1)^2 - 2\,d\bar{x}^1\,d\bar{x}^2 + (d\bar{x}^2)^2 \tag{1.35}$$

Not only does g_{11} show itself again, but also an entirely new type of term. I insist that it has always been there but has been hiding in the guise of zero. Shall we denote the coefficient of $dx^1 dx^2$ by the symbol g_{12}, or perhaps $2g_{12}$? No. We must actually regard it as $(g_{12} + g_{21})$ with $g_{12} = g_{21}$, and then, our tensor being completely revealed, we may finally write equation 1.1 in the form

$$(ds)^2 = g_{11}(dx^1)^2 + (g_{12} + g_{21})dx^1\,dx^2 + g_{22}(dx^2)^2 \tag{1.36}$$

Notice how snugly it fits our notation. It is merely

$$(ds) = g_{ab}\,dx^a\,dx_b = g_{pq}\,dx^p\,dx^q = \ldots \tag{1.37}$$

there being no reason for preferring one letter to another for a repeated suffix because of the implied summation. Because a repeated suffix may be replaced by a different repeated letter it is referred to as a "dummy" suffix, and the changing of repeated suffixes is an important part of the technique of tensor analysis.

We have yet to show that g_{ab} is a tensor. The number of components per co-ordinate system is correct so everything depends on how they transform. This is determined by the fact that though dx^a is a vector, the right hand side of equation 1.37 must be a scalar. We shall here merely *verify* that the law of transformation for the g's is

$$\bar{g}_{pq} = g_{ab}\,c_p^a\,c_q^b \tag{1.38}$$

The proof will not be difficult if the notation is expanded, but it can be taken on trust without what follows becoming incomprehensible. When the co-ordinates undergo the transformation shown in equation 1.8 we want $d\bar{s} = ds$. So, making play with various dummy suffixes, and using equations 1.23, 1.12, and 1.13, we have

$$\begin{aligned}(d\bar{s})^2 &= \bar{g}_{pq}\,d\bar{x}^p\,d\bar{x}^q = (g_{ab}\,c_p^a\,c_q^b)\,(C_c^p\,dx^c)\,(C_d\,dx^d)\\ &= g_{ab}(c_p^a\,C_c^p)\,(c_q^b\,C_d^q)dx^c\,dx^d = g_{ab}\,\delta_c^a\,\delta_d^b\,dx^c\,dx^d\\ &= g_{ab}dx^a dx^b = (ds)^2\end{aligned}$$

A comparison of equation 1.38 with equation 1.14 shows that g_{ab} is a genuine tensor. That it is of the second rank merely means that it has two suffixes.

What use is it now we have found it? Haven't we managed very nicely without it all these years? Apparently so—but in actuality not at all so! We cannot even begin to talk about the concept of distance without implicitly referring to the existence of g. It is as much a part of nature as π or the Maxwell equations, and is always present in equation 1.1, however well hidden. It acts as a counterpoise to the violent fluctuations in the values of the co-ordinate differences dx caused by changes in the co-ordinate system, and throws its weight in the exact direction and to the precise extent needed to keep the value of the quantity $g_{ab}\,dx^a\,dx^b$ absolutely undisturbed. Without some such unchanging quantity as $g_{ab}dx^a dx^b$ the idea of distance could find no mathematical expression, and because of its fundamental role in this connection, g_{ab} is called the *metrical tensor*. Although it is not possible to give a simple picture for g_{ab}, the best in two dimensions being two imaginary lines, we see that it is an objective reality of the first importance. Yet it was not really isolated till the nineteenth century!

The final thing to look for in equation 1.1 is the vector of the type T_a, and before we go after it we must straighten out the whole matter of the two places for putting in the suffixes on a tensor. The law of transformation expressed by equation 1.14 shows that whether a suffix is upstairs or downstairs has a great effect on the transformation law obeyed by the tensor. The two types of suffixes induce complementary types of transformations which, under certain simple conditions, completely nullify each other. Let us look at a simple example of this, which, incidentally, will materially assist our hunt. We consider two vectors of different types T_a, V^a. They transform, under the co-ordinate transformation 1.8, according to the laws

$$\bar{T}_a = c_a^c\,T_c, \quad \bar{V}^b = C_d^b\,V^d \tag{1.39}$$

where we have used such letters for suffixes that we shall not have to make unnecessary changes of dummy suffixes in the later argument. From equation 1.39 we see that the four quantities $T_a V^b$ transform, under 1.8, according to the law

$$\bar{T}_a\,\bar{V}^b = c_a^c\,C_d^b\,T_c\,V^d \tag{1.40}$$

This being precisely the tensor law for a tensor of the type T_a^b, as is easily seen from equation 1.14, it follows that the quantities $T_a V^b$ actually constitute a second-rank tensor. Now let us see what happens when we put $b = a$ so that we have $T_a V^a$ and, by our convention, must sum over the dummy suffix a. The notation is so clever it is well ahead of us! For if a is a dummy suffix and thus summed, it is really lost to us and the notation indicates that we now have a scalar. This is actually the case, since we have, by equations 1.40, 1.13, and 1.12,

$$\bar{T}_a\,\bar{V}^a = (c_a^c\,C_d^a)T_c V^d = \delta_d^c\,T_c\,V^d = T_c\,V^c = T_a\,V^a \tag{1.41}$$

which is the correct law of transformation for a scalar.

Such an equation between tensors as, for example,

$$T_{bc}^a \equiv (2U_{bc}^a - \frac{7\pi}{16}\,V^a W_{bc} + \sqrt{-1}\;X_c^{ad}\,Y'_{bcd}/Z) = 0 \tag{1.42}$$

illustrates all the important rules for manipulating tensors and these are so obvious that to explain them would but confuse matters. Note that we may not divide by tensors, except by the simplest type, scalars; and that if we do not count the dummies, all the terms have the same suffixes.

We now know enough to entrap the second vector in equation 1.1. It is merely the quantity

$$(g_{ab}\,dx^b) \tag{1.43}$$

and we shall leave it to the reader to convince himself of this and to note how the scalar character of the right-hand side of equation 1.37 fits in with the illustration $T_a V^a$ and with the general rules contained in equation 1.42.

And now our hunt is ended.

Should the reader feel disappointment at the size of the bag let him remember that it is neither his fault nor, I hope, mine, but solely that of the tensor calculus itself. We have found traces of almost every important idea in the tensor calculus that does not involve differentiation and there is nothing more to learn in the way of essential general ideas.

It is extraordinary that so apparently empty a subject—a notation plus a law of transformation—should have such vast importance, but we shall find ample evidence of its powers in part III.

In case you are interested, an upper suffix is called contravariant; a lower suffix, covariant. But don't try remembering which is which just yet. It will be obvious after we come to covariant derivatives in part II.

Culture in This Age of Science

In an address reported in a recent issue of *Vital Speeches of the Day*, W. F. G. Swann, director of the Bartol Research Foundation of the Franklin Institute, Swarthmore, Pa., discussed the problem of the use of leisure that has been made available by the accomplishments of science. Although warning that it is difficult to appraise the present in relation to the past and future, Doctor Swann pointed out that one who views the world today cannot escape the impression that the change man has seen in the last hundred years does not find its counterpart in any like period of the world's history.

At the beginning of the past century, humanity was divided roughly into two classes of beings: the man who toiled and whose whole life was spent in the effort to survive, and the man of wealth. The latter had leisure for cultural pursuit; but, even to him, the realms of culture were limited to a few fields, and these he pursued in his own immediate surroundings with but little personal contact with his fellow men, other than the few whom he had gathered as guests around him. It was an age of culture, but culture for the few.

Then new forces came to life. Railroads, electrical machines, and automobiles were created, and that great structure which is modern civilization was being built as fast as it could be planned and constructed in the age of science. The arts associated with culture became left in larger and larger measures to professionals. The skill of the professional increased while the skill of him who lived in the class of cultured listeners of yore decreased as he became more and more an onlooker and less and less a participant.

As an era is approached in which all men, even the workers of humble degree, have time for things other than the battle against starvation, the use of leisure becomes a problem of fundamental importance. Few people are more unhappy than those who have attained middle age and who have never devoted themselves seriously to any constructive pursuit. To be satisfactory, a cultural activity should, like a good game, have in it those elements which render possible continued improvement without the possibility, or at any rate, the easy possibility, of an approach to perfection. In an age in which a large proportion of mankind may look forward to a reasonable amount of leisure in the future, it may become as necessary to provide a basis for the utilization of that leisure as it is to provide for a man's health.

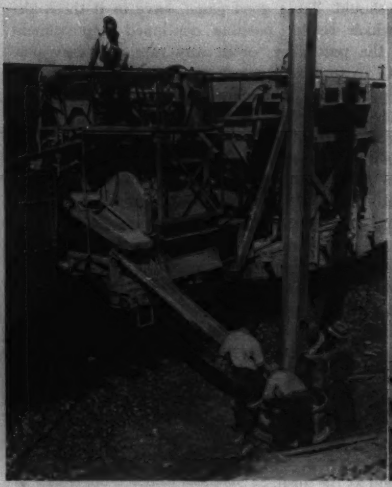
"When one stresses the needs of cultural pursuits," said Doctor Swann, "one is often met by the frown of the utilitarianist, who demands that that which man does shall be of use. But what, in the last analysis, is the purpose of all the things which are 'of use'? The whole world is a gigantic machine with parts of ever-increasing complexity striving toward some goal which as yet seems ill defined. What is that goal? Is it merely security from sorrow, and freedom from hunger and pain? If such is the only goal, universal suicide may well present itself as a worthy candidate to secure that end. If it be not the only goal, there remains the positive realization of happiness, and this state, in which man is happier alive than had he not been born, is the one which I present to you as the ideal. . . ."

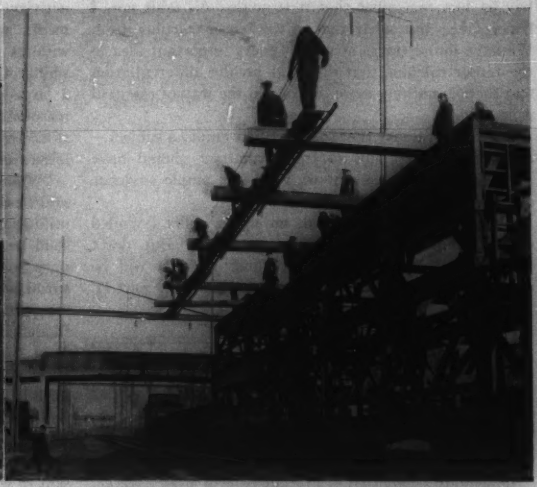
Science may bring to realization an economic state where man need vie no longer with man for possession, and nation need strive no longer with nation for conquest. In this millenium there may be strife, but strife of intellect, which exists among men of science even today. If only the fruits of science could be properly administered throughout the world, this kind of combat would represent all the wars that need remain. Destructiveness would be replaced by a constructive strife.

In conclusion, Doctor Swann said "Great is the heritage which has come to mankind within the generation that now lives; but, the elements of that heritage are disordered in their relationships one to another. The blessings of science can be made to serve many unworthy ends. Even now, in ever-increasing crescendo, we hear the voices of propaganda calling through the appeals of flattery, of humanity, of pride, and all the other portals of weakness in the heart of man, to beguile the spirit of the nation to a strife for principles whose inner content is hard to fathom from the clothes they wear. Great is the responsibility and great the opportunity for one who . . . assumes at this time the task of molding the vision of the nation's youth, that it may know how to judge between propaganda and the voice of truth, that it may recognize greed masquerading in the cloak of righteousness, that it may know reality from shadow, and that it may learn to put what nature has yielded to the service of humanity, and to replace the poisonous satisfactions and greedy hopes which infest the nations of today with the joy which comes from kindliness toward all men."

Extension of The Pennsylvania Railroad's

By H. C. GRIFFITH
MEMBER AIEE





THE EXISTING single-phase electrified system of The Pennsylvania Railroad, completed in the early part of 1935, extends from New York, N. Y., through Philadelphia, Pa., to Wilmington, Del., Baltimore, Md., Washington, D. C., and Potomac Yard, Va., for passenger and freight service north and south; and from New York to Philadelphia and Paoli, Pa., for service east and west. Including the trackage used for suburban service, this electrified system now covers a route of 373 miles with 1,343 miles of electrified track.

The results of this present electrified system have been so satisfactory to the railroad and to the public that the company decided to proceed with an extension which will complete in effect the program announced in the fall of 1928. The lines now being electrified are: (1) The main line from Paoli, 20 miles west of Philadelphia, through Lancaster to Harrisburg for passenger service to and from the west; and (2) the low-grade freight line from Morrisville, Pa., near Trenton, N. J., via Columbia to Enola Yards near Harrisburg; the freight line from Columbia, Pa., following the Susquehanna River to Perryville, Md.; and the freight line from Monmouth Junction to South Amboy, N. J., with connecting branches and yards. This new work involves the electrification of 315 miles of line and 773 miles of track.

In general the same type of system of delivering power to the moving trains will be employed in the extension as is now in use. An 11,000-volt single-phase 25-cycle trolley wire, supported by a catenary type of messenger construction, is used over the center of each track. Transmission from power-supply points to substations is over 132,000-volt single-phase 25-cycle two-wire transmission circuits supported on the same structures that carry the catenary system. Substations, which are of the outdoor type, average from eight to ten miles apart, although in some cases this spacing is as much as 13 miles.

General Features of Construction

Catenary structures are spaced approximately 20 per mile, and the poles are of an H-section, simple and easily adapted to the required designs. The principal structure design is called the "cross catenary," and consists of guyed poles on each side of the right-of-way with a cross-wire span over the tracks to support the weight of the catenary structure. The guy anchors usually are cast-iron cones, but where greater strength is required, a reinforced concrete anchor is poured in place. The pole foundations

Based on a paper presented at the AIEE Middle Eastern District meeting, Akron, Ohio, October 15, 1937.

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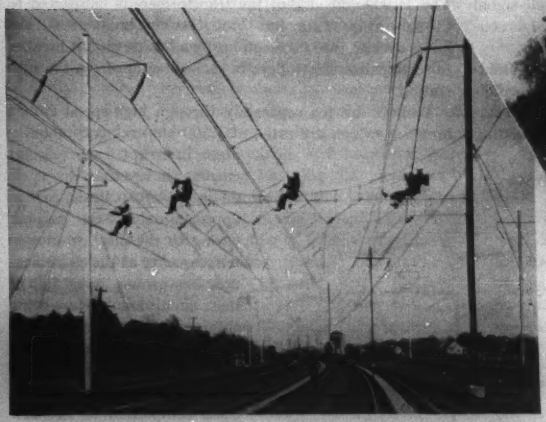
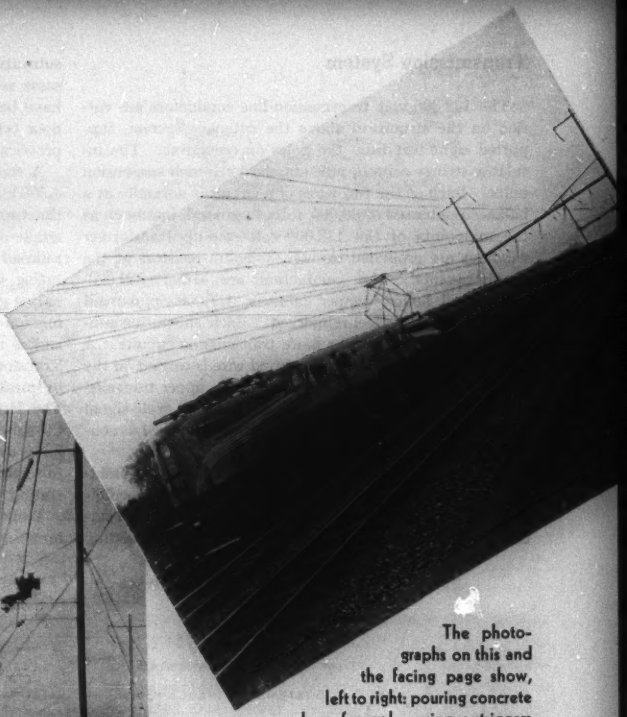
Electrified System

The single-phase electrified system of The Pennsylvania Railroad now in operation includes 1,343 miles of electrified track. An extension, now nearing completion, will increase the number of miles of electrified track to 2,116. Design and operating details of the 11,000-volt 25-cycle system, together with some interesting side lights on protective devices and the communication network, are presented here.





The photographs on this and the facing page show, left to right: pouring concrete base for pole; using outriggers over track kept in use for steam operation; workmen in boatswain chairs, adjusting catenary hangers and attaching wire clips; one of the class-CG1 locomotives in use on the electrified sections

have been simplified, and generally consist of a metal tube sunk in the ground and back-filled with concrete after the pole has been inserted and aligned. The top surface of the foundation is dressed off by metallic split forms.

Where the use of guys is not practical, a self-supporting structure known as the "crossbeam" type is used. The cross-wire span in this type of structure is replaced by a steel crossbeam stiffened by sag braces, by which means the poles are made self-supporting. Where placing poles on each side of the right-of-way is undesirable or unnecessary, such as on one- or two-track construction, and provided one pole only is required for the support of the transmission circuits, a structure known as the "bracket" type is used. This is a single guyed pole supporting a bracket from which the catenary construction is suspended.

An unusual feature of these general types of structure is their large degree of longitudinal and torsional flexibility together with transverse strength.

The catenary system consists of a number 4/0 bronze trolley wire, having approximately 55 per cent equivalent copper conductivity, supported by a five-eighths-inch composite messenger cable having 7 copper-covered steel core wires and 12 surrounding copper wires. This composite supporting messenger provides additional conductivity somewhat greater than the conductivity of the five-eighths-inch low-conductivity bronze wire generally used up to this time, and at the same time furnishes adequate strength for supporting the catenary system. On all tracks used for high-speed passenger service, where greater flexibility in the catenary system is desired, and at points where greater conductivity is required, an auxiliary messenger of number 4/0 solid copper is carried just above the contact wire. This messenger supports the contact wire by means of clips staggered with respect to the hangers, which in turn support the auxiliary messenger from the main messenger. The insulation of the catenary system is ample for maximum reliability, and consists of three ten-inch standard cap-and-pin suspension insulators each five and three-quarter inches in length.

The catenary contact system over each main track is electrically independent of that over other tracks, except as connected through circuit breakers at the substation bus. The trolley wires are sectionalized back of crossovers and at such other points as required to isolate a failure and restrict it to a relatively small section.

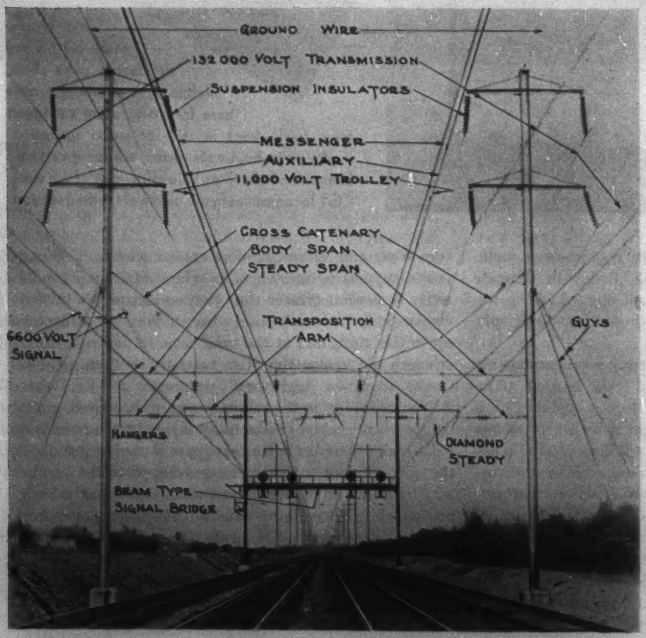
Transmission System

The 132,000-volt transmission-line conductors are carried on the structures above the catenary system, supported eight feet from the poles on crossarms. The insulator strings contain nine standard ten-inch suspension units. Each of the two wires of a circuit is normally at a balanced potential of 66,000 volts to ground, inasmuch as the midpoints of the 132,000-volt step-up transformer windings are grounded through 330-ohm resistors at the supply points. The conductors are either 250,000-circular-mil hollow copper cable or 477,000-circular-mil aluminum cable, steel reinforced. Each substation usually is supplied by two or more transmission circuits. A number 4/0 stranded-copper ground wire is carried on the tops of the poles about 12 feet above the upper transmission wires. A 6,600-volt single-phase 100-cycle-signal power-transmission circuit composed of number 1/0 conductors is carried on the same structures.

This extension of the electrified system involves building 21 additional step-down transformer substations, additions to the transformer capacity in two of the supply stations and changes and additions in many of the existing substations. Generally the design of substations is the same as previously used, except for such modifications as have been made in the interests of economy. The outdoor type of structure used has been simplified as far as practicable.

A step-down transformer with a continuous rating of 4,500 kva has been adopted as standard size, the design of the transformer receiving particular attention to secure ample overload capacity to fit the characteristics of the railroad power load, and to have high impulse-voltage rating with carefully co-ordinated insulation. Co-ordinating gaps are attached to the bushings and to the transmission lines in and near the substations. Lightning arresters usually are not used on the 132,000-volt circuits. Transformers are connected to the transmission circuits by means of horn-gap switches without circuit breakers. The 11,000-volt side of the transformers is connected to the substation trolley bus through circuit breakers and the bus is divided into two sections by a bus tie circuit breaker to sectionalize the trolleys in each direction from the substation.

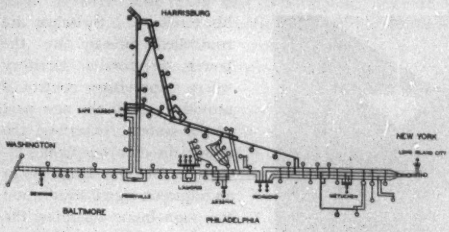
Trolleys are fed separately through high-speed circuit breakers, which are rated at 1,500 amperes continuously and interrupt short-circuit currents in less than one cycle on a 25-cycle basis, or in approximately 0.04 second. Owing to the increase in system capacity as the electrification has grown, over 100 of these circuit breakers are being obtained with an interrupting rating of 65,000 amperes as compared with the previous rating of 50,000 amperes. Upon completion of the new electrification, more than 500 highspeed circuit breakers will be in service. One particular feature of the later designs of these circuit breakers is that they contain little or no oil, which simplifies the maintenance work and greatly reduces the fire hazard in case of damage.



Typical main-line four-track construction with "cross catenary" type of supporting structures and with four transmission circuits. In the background is a signal bridge, simplified and combined with an electrification structure. A transposition in the transmission lines is made at this signal bridge

Special Features

Substations are unattended, and on the present electrification between New York and Wilmington most of them are electrically controlled directly from nearby signal-interlocking towers Equipping some substations with direct control has been found to be uneconomical and supervisory control has



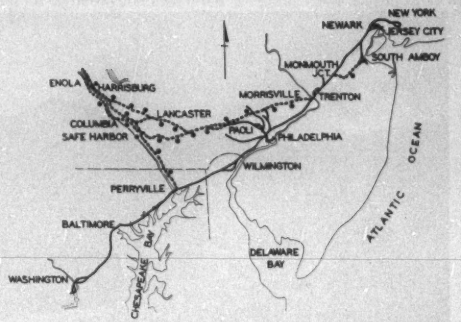


Diagram of the transmission circuit for the electrified system and the extension now nearing completion and (right) a map of the area covered by the electrified lines

been used for the operation of a substation. When the electrified system was extended south of Wilmington to Washington, the most suitable location for several substations was too far from an interlocking tower to make direct control economical and supervisory control with remote metering was used instead for six of the substations. This placed the stations directly under control of the men in charge and has been found to be efficient and reliable and somewhat faster than the previous system of handling the operations by telephone instructions to the interlocking tower operators. The supervisory control system not only provides remote control, but also calls immediate attention by visual and audible means to any automatic operation and provides at all times positive indication of the position of circuit breakers and switches in the substations.

At the present time 14 of the 40 existing transformer substations are operated by supervisory control. Because previous experience indicated the reliability of such a system, a uniform centralized control system for all of the substations on the new electrification was designed. This system is simplified by the location of 18 of the 21 new substations on one railroad division; consequently, all but three substations come under the supervision of one headquarters office, and two of the remaining three could be incorporated as part of an existing system at another point. The remaining substation is located on a freight branch line and will be controlled by supervisory control from an interlocking tower from which is controlled the adjacent existing substation.

The point from which the group of 18 new substations will be controlled is in Harrisburg. These substations are divided into two zones, each zone comprising about half of the main passenger line and half of the low grade freight line. The two-wire "code" type of supervisory control is used, each of the substations being normally operated over a separate pair of telephone wires. The substations are further divided into groups, separating the passenger and freight territory in each zone. Each of these four groups, known as metering groups is provided with a pair of spare wires for emergency operation of any substation in the group. If the wires over which a substation is normally operated should fail, operation can be transferred to the spare wires by remote control from the dispatching office.

At the dispatching office a set of meters is provided for each of the metering groups, and indications are brought over a pair of metering wires for each group. Any one meter reading in each group thus may be obtained at the same time from a substation in the group without interfering with the normal operation of the supervisory control system.

Power Supplies and Parallel Operation

Power at 25 cycles, single phase is supplied to the system at seven separate supply points, and except for the supply from 25-cycle turbogenerators at the railroad's own power plant at Long Island City, N. Y., the energy is purchased from power companies. This energy is obtained from interconnected power company 60-cycle systems, with the exception of one 25-cycle water-wheel generator that feeds the railroad circuits direct, and is converted to 25 cycles by means of frequency-changer motor generator sets. Purchased power is obtained under two separate contracts: one in the area from New York to the Susquehanna River on the south and to the west at a point between Lancaster and Paoli on the new electrification; the other covers the area from the Susquehanna River south to Washington and from the westerly sectionalizing point to Harrisburg and the Enola Yards. This arrangement adequately protects the service by providing power supplies at points well distributed along the route, at the same time permitting the supply of enough power from each source to ensure enconomy of production.

Normally the supply stations are operated in parallel through the railroad's 25-cycle transmission lines. As mentioned before, no circuit breakers are connected in the 132,000-volt lines at the substations to switch the transformers or the lines between substations under load or automatically during faults. Circuit breakers are provided, however, at several points in the 132,000-volt lines to isolate the areas served by the principal supply stations and to separate the two supply systems.

When sectionalizing circuit breakers are opened, corresponding "phase breaks" are opened in the trolleys at the same substation, thus preventing a passing train from momentarily tying together the trolleys fed from separate sources, which may be out of phase. These circuit break-

Load dispatcher's office, with manually controlled model board indicating all transmission lines, power supply points, and transformer substations. Load-totalizing telemeters are shown in the background

ers are opened automatically when the 60-cycle systems back of the 25-cycle generators are out of step. If there is a possibility that this may occur because of lightning storms or during similar emergencies, the circuit breakers may be tripped remotely by an operator at the principal supply stations or in the power supervising office of the railroad company.

Prior to the extension of the electrification to Harrisburg, automatic operation of the 132,000-volt circuit breakers was not provided for short-circuit or ground faults on the railroad's transmission lines, but because extending the system necessitated an increase in the length of the circuits, automatic operation now is provided. This reduces the length of circuit tripped out by the faults, and during a short circuit the principal supply points are segregated to prevent such a fault from causing instability of the system. A line that becomes faulted to ground is relayed in such a way as to trip the sectionalizing breaker in that line only and then to isolate completely the section of line at fault. If a line becomes short-circuited, the relays trip sectionalizing breakers on both the paralleling line and the line at fault, except at Zoo substation, in Philadelphia, where tripping the sectionalizing breakers is not deemed necessary. After the sectionalizing breakers have opened, the section of the line at fault is completely isolated.

Operation of Power Supply and Distribution System

The operating personnel of the substation, trolley switching, and power supply systems has been organized in a manner similar to the train-dispatching organization. Each subdivision or zone of the electrified system has a power director who is responsible for all switching in his territory. Switches are controlled directly by the power directors in territory where supervisory control is provided, as on the new part of the system; otherwise the power director telephones instructions to the signalman in an adjacent signal tower, and the signalman operates the switches. Power directors are furnished with complete telephone service to all switching points over which they have supervision, to the train dispatchers and to all telephones along the right-of-way for the purpose of receiving reports and issuing clearances for maintenance operations. Each power director is furnished with a "model board" on which the circuits in his area are shown in miniature with red and green lights to indicate the positions of all switches, enabling him to know at all times the condition of the circuits and thus to act promptly and intelligently. In the past the model board has been operated manually from a keyboard; however, at Harrisburg the model board for the new electrified territory will indicate most of the operations directly as they are performed by interconnection with the supervisory control system.

In addition, the provision of separate centralized supervision over the transmission circuits and power supplies has been found essential, so that switching and manipulation of circuits locally will not interfere with interdivisional circuits and so that the supply of power will be controlled economically and effectively throughout the entire system. The system load dispatcher, who is located at Philadelphia, is responsible for this supervision. His office is equipped with a model board on which all power supply stations, transmission circuits, and substation connections are indicated. Trolley switching and local circuits are omitted. He is connected by a telephone system to all power directors and power-supply stations; moreover, he is provided with an elaborate telemetering system indicating directly the load on each supply station and the division of load between the sections of the electrification.

Railroad Communication System

One of the important problems involved in electrifying a railroad, although not usually associated with the subject, is the modernization and improvement of the railroad's telegraph and telephone system. Under steam operation the communication circuits usually are open wires on poles located close to the railroad, but physical and electrical co-ordination of these circuits with the electrification requires relocation of the communication cir-

cuits. Between New York and Washington, prior to the electric operation, the railroad's communication lines were placed in cable in underground duct lines; the results were excellent. However, in order to provide equal results at a lesser cost, the communication circuits on the electrification to Harrisburg will be carried in armored cable on treated wood poles along the edge of the right-of-way. The circuits are carefully loaded and balanced and provide a communication system much superior to that formerly in use. The new cables provide for the communication system of the electrification together with its remote metering and supervisory control circuits, as well as the communication system for the general railroad purposes.

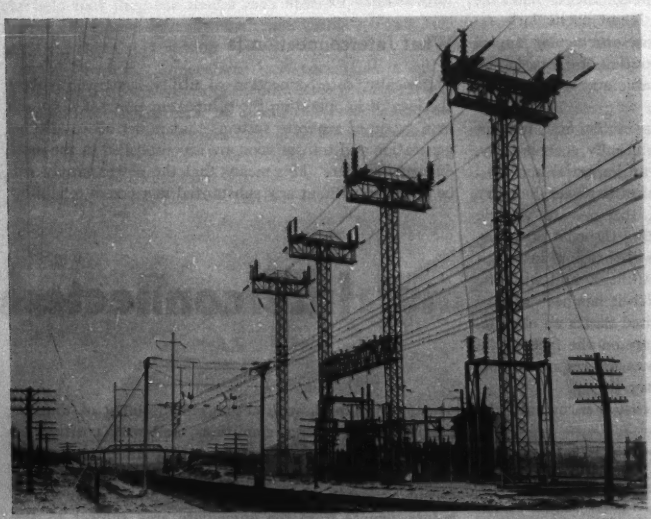
Railroad Signal System

Another important factor in electrification is the arrangement of the railroad signaling system to meet the conditions of electric traction. First, the wayside signal structures themselves must be so located as to be compatible with the location of the catenary supporting structures, and must be so spaced as to provide for the higher train speeds resulting from electrification. Second, since the track rails carry not only the signal circuits but also provide a return circuit for the traction current, the signal system must be designed to avoid interference between the two functions. Finally, the signal system provides for "cab signals," giving in the locomotive cab a continuous indication of the position of the wayside signal last passed, and thus indicating any change in conditions ahead.

The signal system adopted to fulfill these purposes is known as the "universal code" system. "Position light" wayside signals are used, and miniature signals of similar appearance give the same indication in the cab of the locomotive. The d-c or 60-cycle signal systems in use prior to electrification are removed and a 100-cycle universal-code system replaces them. This system provides indications by means of continuously recurring impulses of 100-cycle current in the rails. These impulses, which are transmitted by physical connections to the wayside signal and picked up by the detector bar on the locomotive, by proper tuning and amplifying equipment are translated into the actual signal indication. This signal system is not affected by stray currents of other frequencies, and even should current of the same frequency be imposed on the rails, no false clear signal can result unless the current flows at the proper intermittent coded impulses. This signal system is safe, requires a minimum number of wayside wires, and the over-all cost is relatively low.

At the present time the new work is progressing at full speed. Nearly 10,000 men are employed directly on the project and perhaps as many more are employed in the industries furnishing materials and equipment. This extension, giving complete electrification of the lines from the eastern seaboard to Harrisburg, will effect substantial operating improvements and economies and will enable the Pennsylvania Railroad to realize an increased return on its entire investment in electric service. It will further provide greater reliability, higher speed, and smoother handling of trains, with a consequent benefit to the public. In addition, the new electrification will increase materially the capacity of the railroad, as it did in the present electrified territory, without the construction of more tracks. It will accomplish for the east-and-west movement operating improvements comparable with those gained by the electrification of the New York–Washington service.

After electrification, many heavy steam locomotives now in use east of Harrisburg will be transferred to other parts of the system, thus increasing the efficiency of handling freight and passenger traffic in territory where steam trains are operated. Upon completion of the new work the Pennsylvania Railroad system will have a total of 2,677 miles of electrified track, or 41 per cent of the total electrically operated standard railroad trackage in the entire United States.



One of the new substations, which contains two 4,500-kva transformers and four high-speed trolley circuit breakers, and is fed by two 132-kv transmission circuits entering the substation from opposite directions

The maintenance of reliability and continuity of electric power service is assumed to be an almost inherent function of the local electric utility company; but how much this reliability depends upon the physical interconnection of power systems is not generally realized. An engineer widely recognized as an authority describes here typical operating and economic advantages based upon experiences with an interconnected and co-ordinated system that extends over most of the area east of the Mississippi River.

Huntington, W. Va., was flooded by the waters of the Ohio River during January 1937, as shown here; but the combined facilities of interconnected electric power systems worked together to spare the community from the danger and suffering that follow failure of power service in such areas

Interconnected

THE SUBJECT of interconnection for a long time was linked with its apparently inseparable twin "superpower." Both of these subjects, and particularly the latter, aroused much public interest a decade or so ago, and a great deal of discussion, centered about them. But lately both have received little public comment. That the interest in superpower has lagged is not particularly regrettable, since the word had more spectacular appeal than economic validity. The diminution of discussion on interconnection is less understandable and really is deprecable.

This abatement of interest is lamentable, first, because it is a subject of vast importance technically, economically, and socially; and second because an impartial appraisal of the accomplishments of the electric-power industry in the United States—that is, the private electric utilities in the United States—during the past 50 years, impresses one with the magnitude of the task of interconnecting and co-ordinating electric utilities, and with the magnificence of the manner in which it has been accomplished. This has given to the United States an electric-supply system unparalleled anywhere on the face of the civilized globe, and is in no small measure responsible for the industrial progress in this country.

Yet, the average electric utility customer, or even the engineer not devoting his entire time primarily to a study of the power-supply problem, has little conception of either the work or the products of the work of carrying out interconnection and integration, because his knowledge of electrical systems does not disclose the magnitude and the difficulties of the task.

What Interconnection Is

Basically, interconnection of utility systems involves the idea of so operating the component parts of a system or a group of separate systems that under all conditions generation and transmission are accomplished in the most efficient manner. This means that the power supply will be operated without any substantial sacrifice of reliability of supply; indeed, with actual enhancement of that reliability under normal conditions, and with positive assurance of continuous service during unforeseen emergencies against which no provision is economically feasible, except by making available sources of power supply from points remote from the immediate area subject to the emergency.

The philosophy behind interconnection, then, postulates the idea of unstinted mutual help in times of need,

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Adapted from an address presented at a joint meeting of the local sections of the American Institute of Electrical Engineers, The American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, and the Chamber of Commerce in the Anthracite Field, Scranton, Pa., October 9, 1937.

PHILIP SPORN is vice-president and chief engineer of the American Gas and Electric Company, New York, N. Y. An electrical-engineering graduate of Columbia University, Mr. Sporn started his professional career as a tester with the Crocker Wheeler Electric Manufacturing Company, later becoming affiliated with the Consumers Power Company, Jackson, Mich. He has been associated with the American Gas and Electric Company since 1920; he became chief engineer in 1933, and vice-president in charge of engineering in 1934.

up to the limit where the helper himself is jeopardized. This is important because in other businesses a mutual joining of forces to that extent seldom is permitted to exist. Yet in power systems the idea of operating systems truly interconnected has been closely embraced. It is a sound idea, and sound business, provided that the technique of operating interconnected can be so evolved as to reduce the self-jeopardy of the aiding part of the system, or of the aiding system, to a negligible amount. Those who have analyzed this problem extensively and understand its implications are following it, fully satisfied that it is merely a question of technique, and that the technique of operating successfully on the interconnected basis has been well developed and is being perfected more every day.

From this definition many so-called interconnections apparently are not interconnections in the true sense of the term, because the amount of help they make possible and the resources they offer for emergency use are definitely circumscribed and limited. Figure 1 is an example of a poor interconnection, for between system *A* and system *B* there are two transformations and the maximum power that can be transferred over line *L* is limited not only by the impedance drops through the two transformer banks, but also by the thermal limitations of these transformers. Only rarely is the thermal limitation of the transformers even approximately equal to the thermal limitation of the line itself. Or consider figure 2, in which system *A* interconnects with system *B* and with system *C* through lines *LB* and *LC*, respectively. Here again not only is the extent of help that *A* can render to either *B* or *C* limited, but also in emergency *B* and *C* are limited in the help that they can render each other because of the double impedance drop of transformer banks *TB* and *TC* and their thermal limitation.

Several such interconnections have been built in spite of the fact that the conditions would have permitted the omission of transformers, because those responsible for the interconnection were not certain of the soundness of the idea of operating interconnected systems. But such poor interconnections fortunately have been few, and several interconnections started with that idea subsequently have been altered to operate more closely interconnected.

Electric Power Systems

By PHILIP SPORN
FELLOW AIEE

Achievements in Interconnection

To demonstrate some of the things accomplished by means of interconnection in the United States, the American Gas and Electric Company's system has been chosen, purely for convenience, as a typical interconnected system. Figure 3 shows the system extending into the seven states of Michigan, Indiana, Ohio, West Virginia, Virginia, Kentucky, and Tennessee. It does not show The Scranton Electric Company system extending through the Lackawanna Valley or the Atlantic City Electric Company system covering the southernmost fourth of the State of New Jersey, both of which are parts of the composite system.

The parent company was organized in 1906 and originally owned properties at Marion and Muncie, Ind.; Canton and Bridgeport, Ohio; Wheeling, W. Va.; and others in the surrounding territory. By 1913 these companies had grown and others had been purchased where they could fit in with the idea of integration, which even in those days was a dominating policy in the evolution of the company. This was effected in typical fashion in the Wheeling, Steubenville, and Canton districts. Eventually a need for larger capacity in these districts became evident, and because of the lack of an adequate local supply of cooling water, especially in the Canton area, it became apparent that the most satisfactory way of increasing the generating capacity was to interconnect the properties and serve them from larger and more efficient power stations situated favorably with respect to fuel and water supply. The result was the construction of the history-making Windsor power station, located at the mouth of a coal mine on the Ohio River 14 miles north of Wheeling, W. Va. With it was erected the first 132,000-volt transmission line in the middle western region of the United States and as a consequence the power system throughout an area of several thousand square miles became integrated. Windsor was a historic landmark in another sense: It was the first jointly owned and operated large power station and thus served as an interconnecting and integrating medium between two otherwise separate power groups, the cooperating organization at Windsor being the West Penn Power Company.

This integration of resources was continued over the entire area as new properties that could be so integrated were acquired. During the period from 1924 to 1929 expansion was particularly rapid; properties were "tied together" by high-tension transmission lines, and inefficient generating units were abandoned. By the end of 1929 most of the properties were virtually tied together by a 132,000-volt bus.

By 1925, 132,000-volt lines had been extended from South Bend, Ind., to Lima and Fostoria, Ohio. Previously built 66,000-volt lines connected this region with Philo plant over a long north-and-south transmission network running from Crooksville to Fostoria, Ohio. The lack of proper sites for generating plants in the Canton, Fostoria, and Lima areas, mainly because of the inadequacy of the supply of cooling water, necessitated extending into this area the high-tension transmission system whenever the 66,000-volt system became inadequate. By 1929 the loads in the North and Central Ohio area had grown so much that additional generating capacity was required; consequently, the Philo-Shelby-Fostoria 132,-

000-volt line, which connected the Ohio and Indiana territories, was constructed. Besides satisfying the immediate load requirements this tie effected material savings from replacing energy formerly generated in Indiana by energy produced at Philo and other plants having fuel costs substantially lower than in the Indiana plants. Thus, during the depression and continuing now during all light-load periods, a large part of the generation in Indiana has been replaced by generation at Philo and at other plants in the eastern section. The resulting saving for the past five years on fuel costs alone amounted to, roughly, $1,500,000. To do this, however, required a double circuit

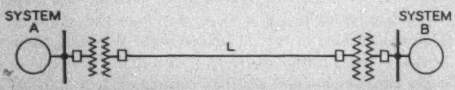

Figure 1. Diagram of a poor type of interconnection between two power systems, in which the maximum power transfer between the systems is limited by the voltage drops in the impedances of the transformer banks and by thermal limitations of the transformers

between Philo and Fort Wayne. This interconnection has produced a further saving by diversity interchange between the American Gas and Electric Company system and the Northern Indiana area, which in turn is interconnected with the Chicago area.

Here, then, is an interconnection, typical of many others, which has paid its way on a basis of economy interchange, has contributed to conservation of natural resources through the utilization of more efficient fuel-burning equipment, and has contributed materially to lower cost of electric service. This interconnected system has a peak load of about 825,000 kw, with an annual energy output of just under 4,500,000,000 kilowatt-hours. This system has also about 20 interconnections with outside companies, some of which are used for emergency operation only; others are for day-to-day interchange. The combined capacity of these interconnections is 550,000 kw.

Similar interconnection and co-ordination has been embodied in the power system serving New York City; on the Niagara-Hudson system, one of the outstanding power systems of the entire world; in California, where interconnected systems having a generating capacity of over 3,700,000 kw operate in parallel; in the Chicago district; in the southern district of the Commonwealth and Southern Corporation, which has a system annual peak of over 900,000 kw with an output of 4,500,000,000 kilowatt-hours; in the system around Philadelphia; in the system of the Pennsylvania Power & Light Company; and in the system of The Scranton Electric Company.

Thus far the discussion has been about the evolution of co-ordination and interconnection on systems representing either one individual company or systems under unified control. But that interconnection has been achieved throughout the country on a vast scale can be seen from an examination of figure 4, which shows the major electric systems and transmission networks in the United States. Except for some gaps which are discussed more fully later, the region east of the Mississippi River is almost completely netted with high-tension lines. Immediately west, is a less dense netting and integration in the Great Central Plains, but the reason for the lessened co-ordination obviously is due to the predominantly agricultural character of much of the territory. The Great Western Plains coming up to the eastern slope of the Rockies have comparatively few high-tension networks. Here the population density and the concentration of industry are too low to warrant or require a high scale of electrical development. A totally different situation exists in the Northwest and on the West Coast. The integration in California already has been mentioned, but nothing has been said about the integration of the systems in Washington, Oregon, and Montana, and on the systems operating over the southern portion of Idaho and Utah. Here, in an area of comparatively great industrial potentialities, power was developed, which in turn helped to develop industry. In the upper central portion of figure 4 is an insert, drawn to scale, showing Great Britain with its 132,000-volt network. Areas containing systems that normally operate in parallel have been marked by cross hatching. Not only is this cross-hatched area highly significant in itself because of the large part of the total area it occupies, but also is particularly interesting in comparison with the area constituting the British Grid. The vastness of the United States, the extent to which netting has

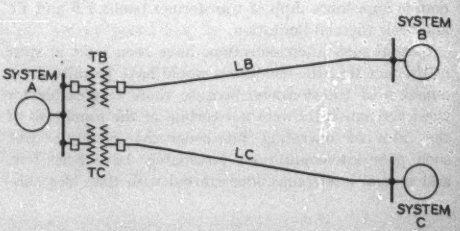

Figure 2. Diagram of a poor type of interconnection between two power systems, in which the maximum power transfer between the systems is limited by a double voltage drop in the impedances of the transformer banks and by the thermal characteristics of the transformers

progressed, and the large areas covered by single networks, spreading in one case to approximately 450,000 square miles, are graphically realized from even a cursory study of this figure.

Some gaps still exist in the integration picture in this country. Reference to figure 4 shows that in some places interconnections actually exist between adjacent large areas in each of which the systems are fully interconnected and continuously operating in parallel. In some places

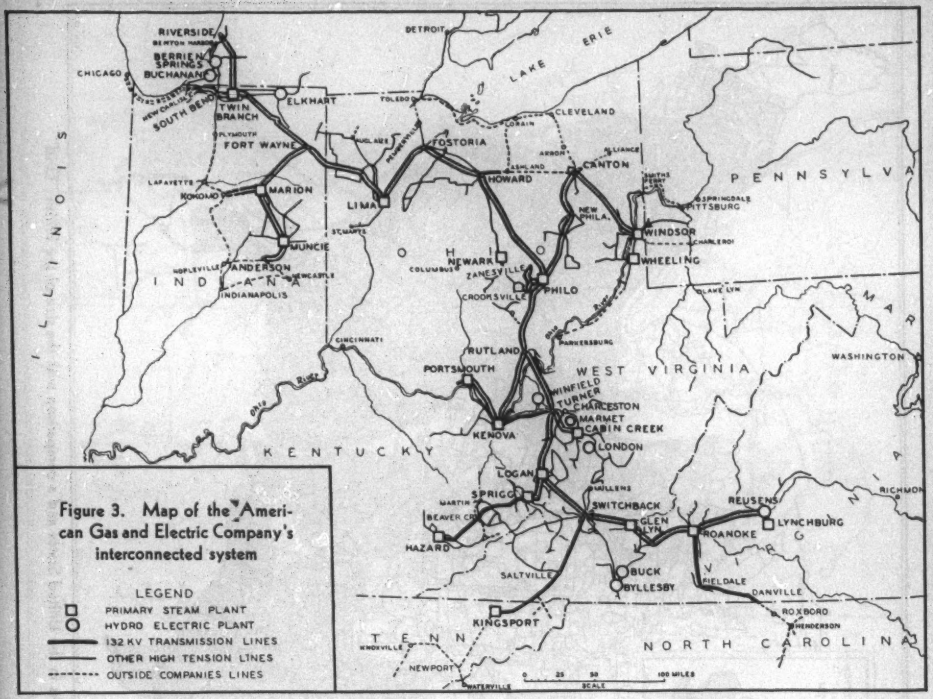

Figure 3. Map of the American Gas and Electric Company's interconnected system

these cross-regional lines provide for all the feasible economies or service protection between areas. In other places, where no ties or weak ties exist, new ties undoubtedly will be made or existing ties will be strengthened as system economics permit. Then, too, there are many places within integrated areas where tie lines eventually will be made heavier or additional ties will be built.

Figure 3 is an example of the integration of individual companies and of companies under the same management; however, in order to obtain the fullest benefits of integration, co-ordination between integrated groups is necessary. In considering a few specific examples figure 5 illustrates the development of co-ordination between the various integrated groups serving the east central and southeastern sections of the United States. This group serves portions of 14 states and covers an area of some 450,000 square miles; it includes a population of roughly 40,000,000. Figure 5 shows also the network of high-tension transmission lines extending over it. The area covered is about 6.7 times the area served by the British Grid, but the population served is only approximately 84 per cent of that served by the British Grid. In December 1936, this interconnected group, operating in parallel, had a simultaneous peak of slightly more than 6,000,000 kw. The combined load curve on that day is shown in figure 6. This is an astonishingly large amount of capacity in parallel and probably is the largest capacity of systems operating continuously in parallel anywhere.

In the northern section of this integrated system steam generation predominates, but in the southern states hydroelectric plants are the chief source of power; moreover, there is a difference in the load characteristics of the various parts of the system. The Chicago area, for example, has a very sharp evening peak during the winter months, but most of the other areas have a peak during the morning. This is typical of industrial areas in the United States.

The interconnection with the Chicago area is through the Indiana & Michigan Electric Company, which is one of the subsidiaries of the American Gas and Electric Company. That company, operating in northern Indiana and Michigan, is interconnected directly with the Northern Indiana Public Service Company, which in turn is interconnected with the Commonwealth Edison Company operating in Chicago. The diversity characteristic between these two areas is particularly striking; the interconnected system of the American Gas and Electric Company has the morning peak characteristic and the Chicago area system has the sharp evening peak. Figure

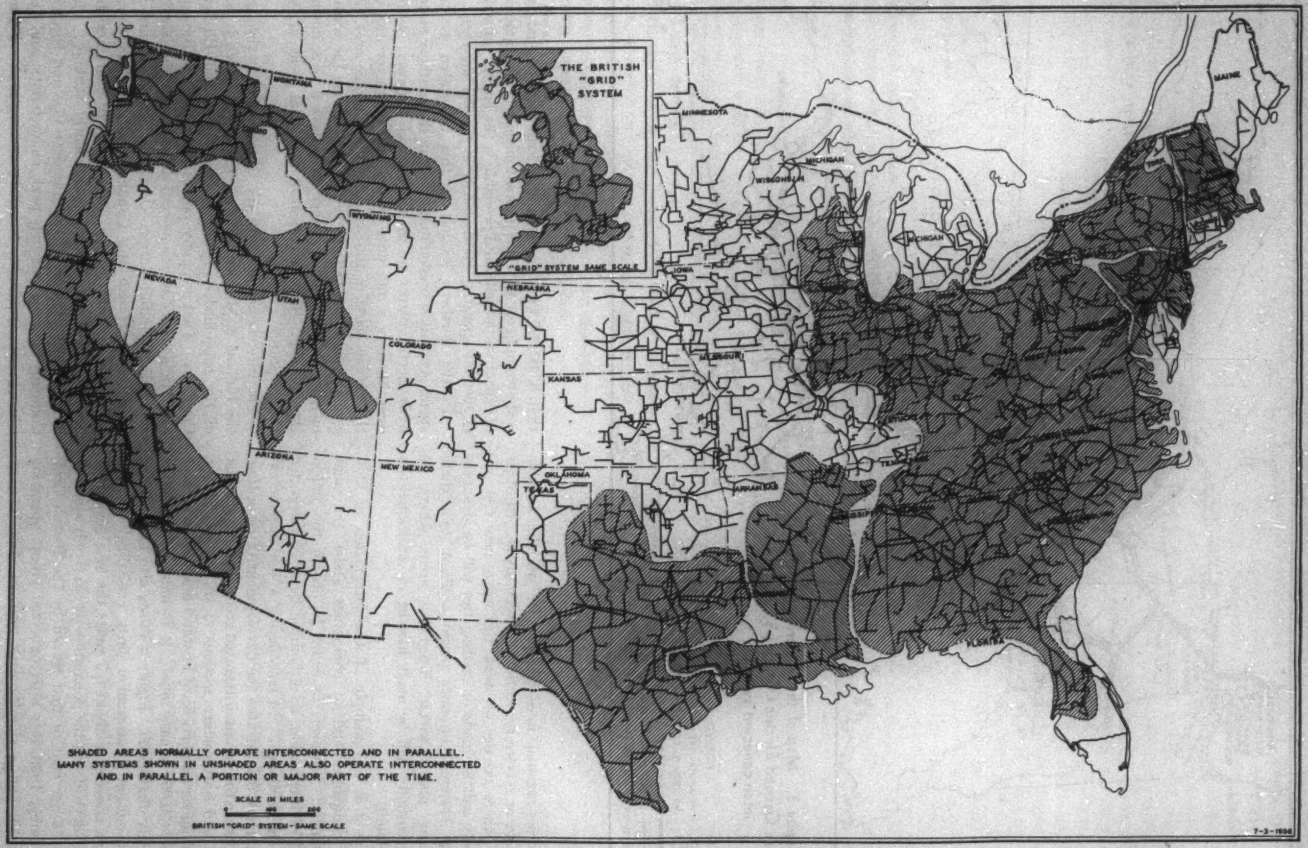

Figure 4. Map showing major electric transmission networks in the United States and a comparison with the size of the British "Grid"

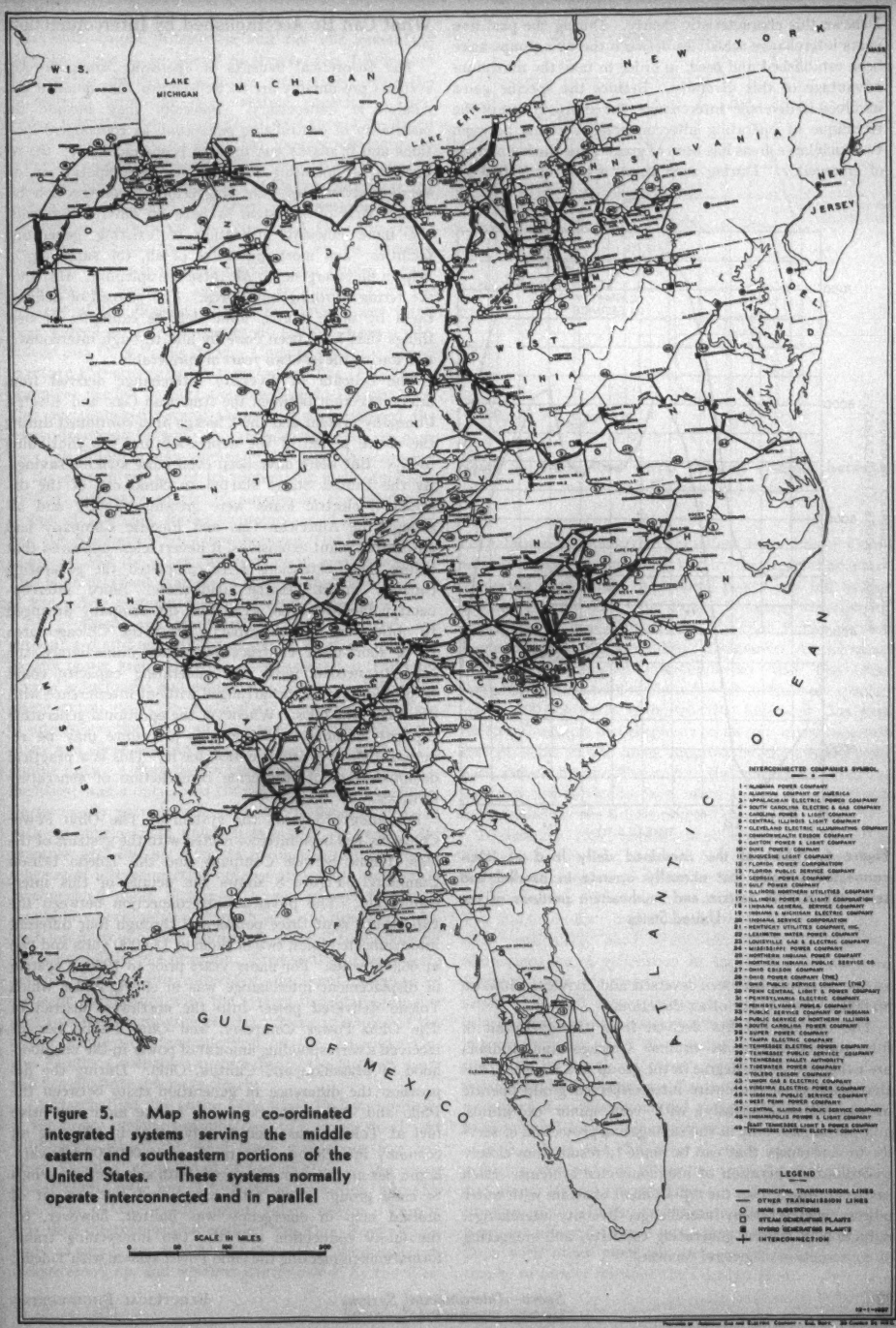
WIS.
LAKE MICHIGAN
MICHIGAN
LAKE ERIE
NEW YORK
NEW JERSEY
WEST VIRGINIA
GULF OF MEXICO
ATLANTIC OCEAN
INTERCONNECTED COMPANIES SYMBOL
1 - ALABAMA POWER COMPANY
2 - ALUMINUM COMPANY OF AMERICA
3 - APPALACHIAN ELECTRIC POWER COMPANY
4 - SOUTH CAROLINA ELECTRIC & GAS COMPANY
5 - CAROLINA POWER & LIGHT COMPANY
6 - CENTRAL ILLINOIS LIGHT COMPANY
7 - CLEVELAND ELECTRIC ILLUMINATING COMPANY
8 - COMMONWEALTH EDISON COMPANY
9 - DAYTON POWER & LIGHT COMPANY
10 - DUKE POWER COMPANY
11 - DUQUESNE LIGHT COMPANY
12 - FLORIDA POWER CORPORATION
13 - FLORIDA PUBLIC SERVICE COMPANY
14 - GEORGIA POWER COMPANY
15 - GULF POWER COMPANY
16 - ILLINOIS NORTHERN UTILITIES COMPANY
17 - ILLINOIS POWER & LIGHT CORPORATION
18 - INDIANA GENERAL SERVICE COMPANY
19 - INDIANA & MICHIGAN ELECTRIC COMPANY
20 - INDIANA SERVICE CORPORATION
21 - KENTUCKY UTILITIES COMPANY, INC.
22 - LEXINGTON WATER POWER COMPANY
23 - LOUISVILLE GAS & ELECTRIC COMPANY
24 - MISSISSIPPI POWER COMPANY
25 - NORTHERN INDIANA POWER COMPANY
26 - NORTHERN INDIANA PUBLIC SERVICE CO.
27 - OHIO EDISON COMPANY
28 - OHIO POWER COMPANY (THE)
29 - OHIO PUBLIC SERVICE COMPANY (THE)
30 - PENN CENTRAL LIGHT & POWER COMPANY
31 - PENNSYLVANIA ELECTRIC COMPANY
32 - PENNSYLVANIA POWER COMPANY
33 - PUBLIC SERVICE COMPANY OF INDIANA
34 - PUBLIC SERVICE OF NORTHERN ILLINOIS
35 - SOUTH CAROLINA POWER COMPANY
36 - SUPER POWER COMPANY
37 - TAMPA ELECTRIC COMPANY
38 - TENNESSEE ELECTRIC POWER COMPANY
39 - TENNESSEE PUBLIC SERVICE COMPANY
40 - TENNESSEE VALLEY AUTHORITY
41 - TIDEWATER POWER COMPANY
42 - TOLEDO EDISON COMPANY
43 - UNION GAS & ELECTRIC COMPANY
44 - VIRGINIA ELECTRIC POWER COMPANY
45 - VIRGINIA PUBLIC SERVICE COMPANY
46 - WEST PENN POWER COMPANY
47 - CENTRAL ILLINOIS PUBLIC SERVICE COMPANY
48 - INDIANAPOLIS POWER & LIGHT COMPANY
49 - EAST TENNESSEE LIGHT & POWER COMPANY
TENNESSEE EASTERN ELECTRIC COMPANY
LEGEND
PRINCIPAL TRANSMISSION LINES
OTHER TRANSMISSION LINES
MAIN SUBSTATIONS
STEAM GENERATING PLANTS
HYDRO GENERATING PLANTS
INTERCONNECTION
SCALE IN MILES
0 50 100 200

Figure 5. Map showing co-ordinated integrated systems serving the middle eastern and southeastern portions of the United States. These systems normally operate interconnected and in parallel

7 shows this characteristic clearly. During the past five years interchange schedules between the two groups have been established and used, in order to take the maximum advantage of this diversity. Besides the specific gains involved in diversity interchange, the improvement of the technique of operating interconnected systems between two such large areas has been of great value during periods of emergency. During such times a flow of 50,000 kw

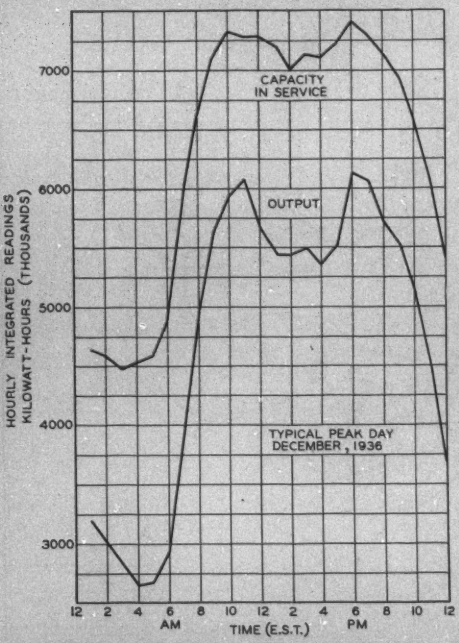

Figure 6. Chart of the combined daily load of interconnected systems that normally operate in parallel and serve the middle eastern and southeastern portions of the United States

in one direction has been reversed and converted into an 80,000-kw flow in the other direction.

The mutual benefits derived from the operation of interconnected systems around Chicago and Indiana are evident to some degree in the group as a whole. Thus the members of the entire interconnected group operate in parallel continuously, with very minor exceptions, and participate fully in the savings and protection of service to consumers that can be made to result from closely co-ordinated operation of interconnected systems. Such savings proceed from the replacement of steam with water power, steam economy interchange, diversity interchange, reduction in reserve generating capacity, and staggering of construction of general facilities.

What Can Be Accomplished by Interconnection

The theoretical benefits of operating interconnected systems presumably are so well-known that detailed discussion is unnecessary. Basically they include the possibility of centralizing generation at economical locations and in plants and units of economical size; the reduction of operating reserve; the participation in diversity advantages; the staggering of construction between parts of a system or between different systems; the more efficient utilization of existing generating facilities; and most important of all, the supplying of help in an emergency. All these are splendid. But they are terms—nothing but words. And instead of defining them by more words, some definite examples of new things that have been done by and through interconnection during the last two years are preferable.

The benefits of diversity interchange derived from interconnection between the American Gas and Electric Company system and the Chicago area continued during the entire period of the depression and are continuing today. But there have been even more striking savings. As the United States started to climb out of the depression, electric loads were growing rapidly and although the American Gas and Electric Company had authorized plant extensions, it nevertheless appeared that before these extensions were completed the generating capacity might become inadequate. Since interconnection facilities were available, the company arranged to obtain the needed capacity from the Chicago area by a short-term contract providing immediately the capacity needed until new generating capacity could be provided; this was arranged without interference with diversity schedules. Whenever the additional generating capacity becomes available this procedure may be reversed if there is any occasion for it. This is a practical demonstration of staggering construction of generating facilities.

For about 15 years the system of The Ohio Power Company has been interconnected with the systems of the Ohio Public Service Company and the Toledo Edison Company. Figure 8 shows the details of this interconnection. The physical interconnection between the two groups is at three points and through four different interconnected lines, two of them at 132,000 volts and two at 66,000 volts. For many years prior to 1930, a system of displacement interchange was in effect, under which Toledo delivered power into the northwest district of The Ohio Power Company, and Ohio Public Service received a corresponding amount of power in the neighborhood of Massillon and Canton, Ohio. During the depression the difference in generation costs between the Philo and Toledo plants, owing to the more expensive fuel at Toledo, was used to advantage in effecting an economy interchange. As much as 10,000,000 kilowatt-hours per month was exchanged, with substantial savings to each group. This interchange and the amount of mutual help in emergency was limited, however, by the 66-kv connection and the two intervening transformations connecting the Ohio Power system with Toledo.

As loads began to increase and the idle generating capacity began to be placed in service, the Toledo and Ohio Public Service Companies were faced with the problem of increasing their system capacity. Their studies indicated that an additional unit should be placed in the Warren plant to meet the load requirements in that area. Joint studies with The Ohio Power Company indicated, however, the economy of placing the generating unit at Toledo instead of Warren and strengthening the interconnection between the Toledo and The Ohio Power Company systems by building a 132-kv tie between them. To make it possible for the Ohio Public Service Company to meet its load area requirements in the territory of the Warren plant, The Ohio Power Company agreed to furnish energy at Canton from Philo. Toledo and Ohio Public Service Company jointly agreed to return this energy at Fostoria, where The Ohio Power Company needed it, over the new Toledo-Fostoria line. This accomplished several things: It strengthened the interconnections between the three companies; it gave the Ohio Public Service Company the necessary capacity on the eastern section of its system; it made available another necessary source of supply to the northwest section of The Ohio Power Company; and it paved the way for economy interchange between The Ohio Power Company and the other two systems in greater volume. This is an excellent example of co-ordinated development of two power systems, under different management.

All of these, and many others could be cited, are without a doubt splendid examples of what can be done by any power group applying itself intensely to the solution of a technical and economic problem as difficult as interconnection. They particularly reveal the soundness of interconnection from an investment standpoint, if the plans and ideas are carefully executed. A utility has a double duty: a duty to the public for which it provides facilities; and a duty to its bondholders and stockholders, whose money provides the necessary facilities to proceed with no improvement unless it is sound. It cannot, for example, and has no right, to indulge in any grandiose schemes of interconnection because they fit so well into a preconceived paper picture of how a group of systems should be co-ordinated. Nevertheless, one must recognize that too narrow a view frequently will fail to disclose all the potentialities of a situation. Frequently the immediate benefit from an interconnection does not compare in value or significance with the system benefits obtainable under extraordinary emergencies. Some examples of the achievements of interconnection on the American Gas and Electric Company's system during the last two years will demonstrate this more clearly.

In March 1936, the entire Ohio River Valley, especially in the upper region, was subjected to a severe flood. At Pittsburgh, where the flood stage was about five feet above the all-time record of 41 feet in 1763, all the major power plants were forced to suspend operation, and this was true of the entire upper valley region. During this time interconnection enabled The Ohio Power Company to supply the facilities of the entire Windsor plant, (which stood up, and which is jointly owned by the West

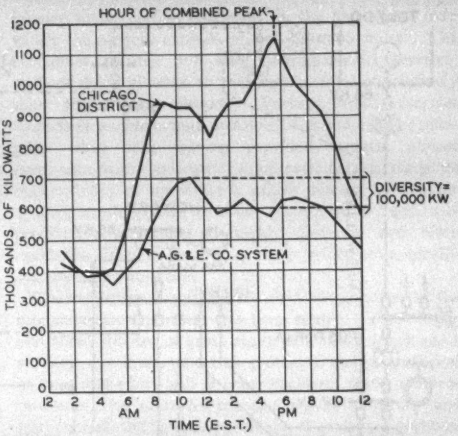

Figure 7. Daily load curves showing diversity between Indiana and Chicago (Ill.) areas

Penn Power Company) to the West Penn Power Company to replace the capacity lost by this and other interconnected companies. Additional power was fed to the stricken area by The Ohio Power Company through its interconnections at Canton with the Ohio Public Service Company and the Ohio Edison Company. At the same time other companies interconnected with The Ohio Power Company stood ready to furnish additional capacity up to 100,000 kw. Although the American Gas and Electric Company lost no plants on its own interconnected system, some of the areas supplied by the system were hard struck by the floods, but the system was able to maintain full service in those areas and to furnish all the help needed by the interconnected companies.

In January 1937, another flood occurred in the Ohio Valley, but this time, although the upper region was not seriously affected, the flood in the lower valley region was unprecedented. The sections around Huntington, W. Va., Ashland, Ky., and Portsmouth and Ironton, Ohio, were particularly hard struck by the flood, requiring discontinuance of generation in the 40,000-kw plant at Kenova (near Huntington, W. Va.), which normally serves this local area. However, as a result of strong interconnections with other parts of the system, service was available at all of these points. Farther down the river at Cincinnati, all power plants were out of commission and the American Gas and Electric companies were part of an interconnected group that supplied power to Cincinnati during this emergency.

In July 1935, the 85,000-kw Glenlyn plant in Virginia suddenly was put out of service by a local cloudburst, and about 100 men worked for a week to get the plant running again. In the meantime customers in that area were not affected in any way, since strong interconnections with other parts of the system mantained continuity of service without the Glenlyn plant.

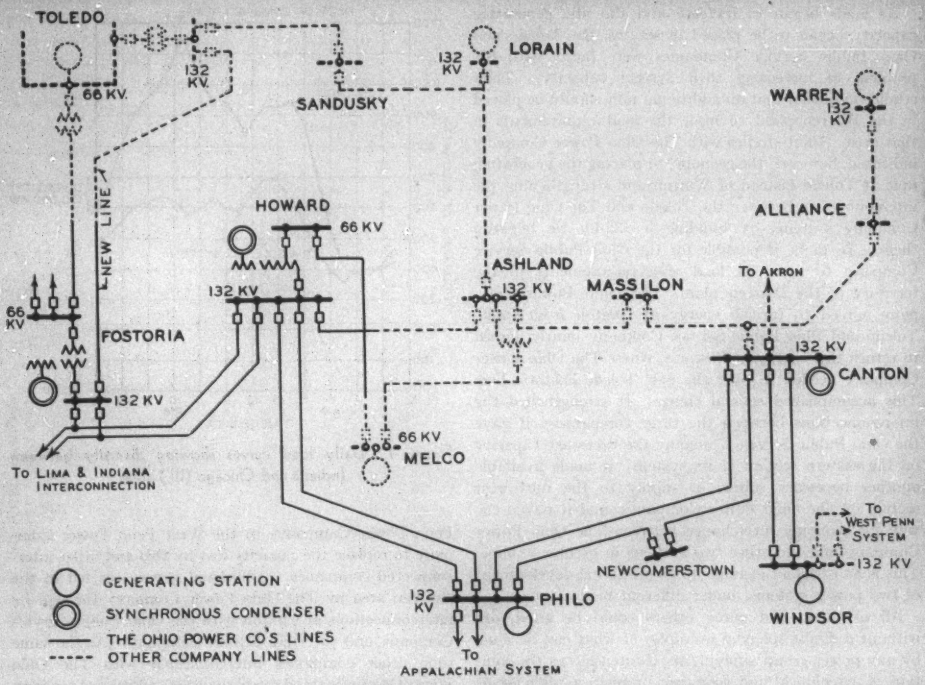

Figure 8. Diagram of the interconnection embracing The Ohio Power Company, Ohio Public Service Company, and Toledo Edison Company

During the flood of March 1936, the Susquehanna River reached a flood stage that was the highest on record since 1846. On March 13 the river reached an elevation of approximately 555 feet, or 25 feet above normal at Stanton plant. The plant maintained service during this period without trouble, and the river then receded; but on March 16 the river again began to rise in consequence of further heavy rains over the entire watershed. During the following day the river started to rise very rapidly and by 9:30 a.m., March 18, the river elevation was 556 feet, $3^1/_2$ inches, which was 1 foot, $3^1/_2$ inches above the basement floor level. The entire yard surrounding the station was flooded and barricades were placed around all doors and other openings where water was finding its way into the building. The water level was beginning to rise and it was found impossible to barricade the building sufficiently to keep the plant in operation. It was then decided that number 2 unit should be taken out of service to permit the removal of motors from the lower levels to prevent flooding of the windings. At 11:58 a.m. the river elevation, 557 feet, 1 inch, was still rising, and so much water was coming into the building that the pumps were overloaded and the boiler-room basement and ash pits began to fill up. Number 1 unit then was immediately taken out of service and the operators were ordered out of the lower stations in the building to prevent loss of life. Power was shut off in the flooded area to prevent damage to electrical equipment. A hot-well pump motor from each generating unit was removed to a higher level and the motor of one circulating pump was removed from the pump room. At the time the men were removed from the pump room they were working $38^1/_2$ feet below the level of the river.

Number 2 unit was taken out of service at 10:30 a.m. on March 18, and was out of service until 6:45 a.m., March 30, or a total outage of 284 hours and 15 minutes. Number 1 unit was taken out of service at 12:02 p.m. on March 18, and it was out of service for a total of 259 hours and 28 minutes before it could be placed back in service. This unit actually was not placed back in service previously because it had been scheduled for the annual overhaul.

During this time interconnections with the Pennsylvania Power & Light Company were maintained. During the Stanton outage the Suburban plant, normally a standby plant, was operated at its full capacity of 50,000 kw. On some days during the day peak a small amount of help from the Pennsylvania Power & Light Company was necessary, but during off-peak hours Suburban was operated and energy was fed back to Pennsylvania Power

& Light Company. But the important point is that continuous service was maintained throughout the entire period. Although some assistance was required at times, during other periods when the system load was less than normal the neighboring systems could be aided. The Binghamton territory also suffered from heavy floods and all of the generating equipment in that territory was out of service. The interconnection between Peckville and Binghamton was operative during this entire period and the Scranton Electric Company supplied Binghamton throughout the flood period.

In each of these emergencies interconnection came through with flying colors and saved the service, because the interconnections were not half-hearted and because the systems had been operated for years with that end in view. Moreover, interconnection was in the front rank of the forces sustaining dozens of communities that otherwise would have had added to the normal ravages of a flood the misery and great danger to life and property following the loss of electric service.

These experiences have been matched by dozens of similar experiences on other systems, but the author purposely has limited the examples to the range of his own experience. Nevertheless, all of them prove that by developing the idea and consistently following the theory of operating systems interconnected, capital and operating economies may be made possible; some provision against catastrophies may be made, and service may be maintained under emergency conditions frequently not even envisioned.

In all of this no long distance transmission of power is involved. Those who have studied the problem of transmission closely, and who thoroughly understand the economics of power supply, know that there is no sound economics in long-distance transmission of power. On the American Gas and Electric Company system, for example, the actual mean weighted distance of transmission under normal conditions in the nine states over which the system extends is less than 60 miles. The economies pointed out were accomplished, therefore, without doing violence to that fundamental of relatively short transmission distance. Further, these examples emphasize an important principle of sound system planning: that after having provided against almost every conceivable emergency in operation and in the great responsibility of operating a utility system, to provide against contingencies wholly inconceivable and unpredictable sometimes is highly desirable and often necessary. This, in general, can be provided economically only by interconnection.

The reader must not believe that the solution of the interconnection problem has been simple. There were, and there still are, a great many difficulties involved in working out interconnection problems, and a great deal of time and effort still is being spent on many of these problems: for example, the problem of frequency and load control, the lightning problem, the relaying problem, and the problem of stability. But the important thing to remember is that, difficult as it has been, the broad interconnection problem has not been shirked because of technical difficulties. It has been carried forward because through the proper application of interconnection and co-ordination electric utility companies have been able to provide better service, cheaper service, better-protected service, and even safer investment. Above all and under all conditions they have been able to get the satisfaction and the peace of mind that come from a definite knowledge that the utmost that can be done by a progressive art and by the intelligent application of capital has been done to assure a proper discharge of the responsibility assumed in undertaking to render utility service. And that this responsibility has been discharged by the utilities of the country in general is a fact that is known to power system engineers the world over.

Figure 9. During the flood of March 1936, along the Susquehanna River the water reached the highest flood stage recorded at any time since 1846. The Stanton plant, situated near West Pittston, Pa., was badly flooded, as shown here, and was forced out of service. Service was maintained in the area served by the Stanton plant by other plants in the interconnected system

Electron Theory

By R. G. KLOEFFLER
FELLOW AIEE

A brief and simple picture of electron theory, this article is intended for those readers who are not familiar with the more recent theories and who have followed branches of the profession not dealing with electronic devices. The electron is shown to be part of the atom, and to be the means by which electricity flows. Its function in electron tubes is explained, and the operation of amplifiers, rectifiers, and photoelectric cells of various types is discussed.

THE DISCOVERY of the electron dates back to the beginning of the present century. This important event was foreshadowed by many early experiments and theories. In 1725, DuFay discovered that the gaseous region around a red-hot body would conduct electricity. In 1879, Crookes found that the rays in his experimental tubes were negatively charged particles. Edison's experiments with the incandescent lamp led to the discovery in 1883 that an electric current did flow from an incandescent filament to a plate in a vacuum but that it would flow in only one direction. This is known as the Edison effect. J. J. Thomson is generally given credit for the discovery of the electron because of his experiments and reports to the scientific world in a period shortly before and after the year 1900. He developed a very ingenious method for measuring the charge on the ion and secured an approximate value of the magnitude of that charge. Wilson and other scientists made some improvements on Thomson's method and secured other approximate values for the magnitude of the charge of the electron. It remained for an American physicist, Robert Millikan, to make further refinements in the method of measuring the magnitude of the charge and thereby secure results announced to the world in 1913 which were absolutely convincing as to the existence of and the value of that fundamental electrical charge on the electron. This electron was a minute indivisible negative charge of electricity having a very small mass. The term electron has always been associated with the negative charge while the term positive electron has been associated with another complimentary unit, the proton.

Four years ago a cosmic-ray photograph taken at the Norman Bridge Laboratory showed unmistakable evidence of the track of a particle having the same mass and the same magnitude as the charge on the electron but of the opposite sign. Thus was discovered the true positive electron, or what is often termed the positron. This recent discovery of the positron has raised many questions in the scientific mind and has tended to upset some of our well-accepted theories regarding matter.

Nature of Electricity

The scientific world has offered many theories regarding the nature of electricity. Benjamin Franklin's single-fluid theory was one of the first. His theory pictured a colorless, weightless, invisible fluid or "electrical fire" which could permeate all matter. A normal amount of this fluid caused a body to be neutral, an excess amount produced a positive charge, while a deficiency gave rise to a negative charge. Later theories were offered by Faraday, Maxwell, and others. It remained for the discovery of the electron to give a definite basis for theories and conceptions which would come nearer to satisfying the inquiring mind of man. Up until 1910 or later, it was generally conceded that no one knew anything of the nature of electricity, though men understood quite well many of the characteristics, properties, and laws of magnetism, electric charges, and electric currents. The general acceptance of the electron gave rise to new theories and conceptions in the fields of chemistry, physics, and electricity. The molecule had been long considered the smallest divisible part of matter, the atom the smallest division of an element, and now the electron, an indivisible and fundamental electric charge, a mere speck of electricity, became a part of the atom. Science gave the electron a mate, a proton, or a positively charged particle having the same charge as the electron but a mass 1,834 times as large. Then these two fundamental building blocks, the electron and the proton, became the basis of all chemical elements. The difference between the elements was determined by the number of pairs (electron and proton) going to constitute the atom. Bohr furnished a mechanical model or picture to show the structure of the building blocks within the atom. This model (figure 1) envisions a structure like a small solar system having a nucleus surrounded by one or more particles moving in orbits. The nucleus has a positive charge and contains all of the protons in the atom. It may also contain a part of the electrons, with the remainder of the electrons moving in orbits about this nucleus. The hydrogen atom has the simplest structure. It consists of a single proton constituting the nucleus with a single electron revolving in a surrounding orbit (figure 2).

To get a conception of the relative physical size of this hydrogen atom, all parts of the atom may be imagined to be expanded until the nucleus, which is the proton, has the diameter of a baseball and is placed in Dallas, Texas. Then the lone planetary electron will revolve in an orbit which passes through New York City and San

Written especially for ELECTRICAL ENGINEERING, based on a lecture given originally at the AIEE South West District meeting, Dallas, Texas, October 28, 1936.

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Francisco, and the size of this expanded electron will be 300 feet in diameter, or about big enough to rest comfortably in a football stadium or a baseball park. This picture shows the relatively "big hole" or empty space in an atom and explains why some electrons and atomic particles may be projected through many atoms before being stopped.

In order to explain radiation phenomena, Bohr assumed that there are a number of possible orbits in which the revolving electrons may move and that the jumping of

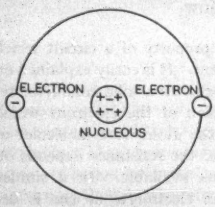

Figure 1. Structure of the atom according to Bohr

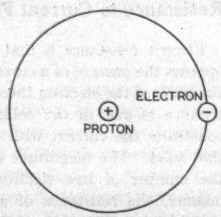

Figure 2. Structure of the hydrogen atom

the electron from one orbit to another is due to the absorption or radiation of energy. Consequently, the orbits are often referred to as energy levels. The orbits are pictured as circles or ellipses and usually as a combination of both in order to explain various atomic phenomena.

At the time when many electrical engineers were in the college classroom, teachers did not attempt to give any physical conception of the phenomenon of electricity or of the units of measurement which were employed. The scientist, the teacher, and the student of former days accepted electrical phenomena as a matter of fact, and, in common with the layman, said, "We do not know anything of the nature of electricity." Today there are some conceptions which have arisen from the discovery and measurements of the electron and from our pictures of atomic structure. Thus, to take the case of the phenomenon of attraction and repulsion of charged bodies, a positively charged body is one in which a large number of electrons have been removed from the body so that the total number of positively charged protons exceeds the number of electrons present. Thus the body has a strong attraction for electrons and it is said to be positively charged. In like manner, a negatively charged body has an excess of electrons above protons and this body exerts a strong attraction for protons, an excess of which may be found in a positively charged body.

Electric Currents

Two bodies oppositely charged have a difference of potential between them. A difference of potential or voltage is measured by the work required to carry a unit positive charge from one body to another against the force of attraction or repulsion. The magnitude of the difference of potential depends upon the concentration of the charge and not on the amount of the charge. Thus an excess of a billion electrons on a sphere ten centimeters in diameter would have only one-tenth as much potential as it would have if concentrated on a sphere one centimeter in diameter. The 110 volts at the ends of a lighting circuit are due to an enormous concentration of electrons along one wire and a corresponding deficiency in the other. When a human being contacts this circuit, the excess of electrons in one wire attempts to pass through the body to the other wire with a result well understood as far as one's feeling is concerned.

If a positively charged and a negatively charged body are brought in contact, electrons from the body with negative charge (excess of electrons) will move over to the body having the positive charge (deficiency of electrons) until an equilibrium of charge has taken place. This transfer of electrons from one body to another constitutes an electric current. Thus we can picture the phenomenon of electric current as a transfer or co-ordinated movement of electrons along a path or circuit. The protons do not move in solids because their mass is 1,834 times as great as the electron, and because of their firm attachment to the atom itself. The magnitude of an electric current is determined by the number of electrons which pass a given point in a circuit per unit of time. To produce an electric current of one ampere, 6.3×10^{18} electrons must pass a point in one second. The individual electrons may move along the circuit slowly or quickly. Thus in a high-voltage vacuum tube, the electrons may move with a velocity approaching that of light, whereas in another part of the circuit they may drift along at a "snail's pace" of only a fraction of a centimeter per second.

The direction of the movement of electrons in an electric circuit is opposite to the conventional direction of current as adopted by scientists many years ago. Thus the early choice of direction of current was unfortunate in that it complicates conceptions and explanations in electronic devices. All remarks in this discussion will pertain to the direction of electron movement.

Current Flow in Solids and Liquids

An electric current in a solid is due to the movement of "free" electrons along that solid. The "free" electrons are not "extras" or those electrons above the normal number to balance the protons, but rather electrons which at certain instants are free from their parent atom to be moved on to another atom in a sort of relay race. Although the molecules are close together within a metallic solid, they do have a movement due to thermal kinetic energy and this movement increases with the temperature. The electrons, in turn, have a movement about their nuclei and at certain positions, due to the molecular action and the electron action, the electrons may become as close to the nuclei of other atoms as their parent. At that instant the urge resulting from a difference of potential can easily move these free electrons along the circuit.

The passage of an electric current through a liquid is easily understood on the basis of the electron theory.

Distilled water is practically an insulator but when an acid or base is added to the water, it becomes a conductor. It appears that part of the molecules of the added material automatically disassociate into fragments or ions. Thus hydrochloric acid separates into H+ and Cl− and sodium chloride into Na+ and Cl−. This means that the H and Na atoms constituting the positive ion have lost one electron and are positively charged. In a similar manner, the Cl atom has an additional electron and carries a negative charge. If a difference of potential is applied to electrodes in the solution, the negative ions will travel to the positive electrode and give up an electron. In like manner, the positive ion will travel to the negative electrode and take on an electron. Thus the ions serve as carriers to convey electrons through the solution and this movement of electrons constitues the electric current.

Current Flow in Gases

Conduction of electricity through gases is produced through the medium of ions as in a liquid but the ions are produced in a different manner. Gas ions may result from the bombardment of gas atoms by high-speed electrons or ions, and by the action of electromagnetic waves of suitable frequency. If a high-speed electron is projected into a gas, it will collide with some of the molecules of that gas. The collision usually occurs with the electrons in the outer orbits of gas atoms. The result may be merely the change of direction of the flying electron or it may be the actual removal of an electron from the outer orbit of the gas atom. When the disruption of the atom takes place, the remaining part of the atom has lost an electron, is positively charged, and is called a positive ion. The electron which is removed may remain a free electron and as such it is a negative ion. It may join another neutral atom and thus form a negative ion of a different kind as far as mass is concerned.

The two gas ions formed by the bombardment of a single electron will move to electrodes having a difference of potential and placed within that gas. In transit to the electrodes these gas ions will collide with other gas molecules and if the difference of potential is sufficiently high and other conditions favorable, these collisions will result in the production of other gas ions. The latter ions may likewise produce still others while in transit to their respective electrodes. Thus ionization of a gas becomes somewhat accumulative in action and fairly large currents may result.

The collisions of electrons and ions with atoms are probably not physical contacts as when a baseball bat hits a ball, but rather the repulsion between the charges on the individual electrons and ions. The molecules of a gas are in a constant state of violent motion and the electrons, in turn, are moving about in their respective orbits. It can readily happen that the relative directions of motion of the electrons are such that an electron is caused to leave its parent atom and produce ions.

An interesting by-product of ionization occurs when a colliding electron does not have sufficient velocity to produce ionization but does cause an electron in an outer orbit to jump to another orbit of higher energy level. The energy absorbed by this change of orbit is released in the form of a visible electromagnetic wave as soon as the electron drops back into its original orbit. The visible radiation or light is of a color characteristic of the element constituting the gas molecule. Frequently the light is monochromatic. This principle of light production underlies all of the gaseous and vapor electric illuminating sources such as the neon, mercury-vapor, and sodium-vapor lamps.

Resistance to Current Flow

Electric resistance is that property of a circuit which opposes the passage of a current. It is easily explained on the basis of the electron theory. In a solid conductor resistance is due to the collision of the electrons which constitute the current with the atoms and molecules of that solid. The magnitude of the resistance depends on the number of free electrons available. In a similar manner, the resistance of an electrolyte or gas is determined by the number of ions produced and by the number of collisions between the moving ions and the molecules present. The influence of temperature on resistance is readily explained. In a pure metal a rise in temperature increases the kinetic thermal energy, speeds up the motion of the molecules, and hence tends to increase the number and the violence of the collisions, thus increasing the resistance.

It is of interest to note that the "hither and yon" movement of free electrons in solids does produce infinitesimal differences of potentials or voltages at the ends of conductors. These minute voltages introduce noise termed "resistance noise" in high-gain amplifiers and limit the smallness of signals which can be amplified satisfactorily.

Electronic Devices

The first electronic device was the two-electrode tube patented by Fleming in 1903 and known for several years as the Fleming valve. It took the place of the coherer as a detector of wireless telegraph signals. This device has grown to be the detector and the rectifier of our modern electronic application. DeForest added a third electrode or grid to the Fleming valve and patented the three-electrode tube in 1907. For many years it was known as the DeForest audion. This device was primarily an amplifier of electric current, and it constitutes one of the greatest inventions of this century.

Freeing Electrons From Solids

The operation of most electronic devices depends upon the removal of electrons from solids in some manner. One method for removal is accomplished by impact on the solid of an electron, an ion, or the nucleus of an atom. A violent impact may splash electrons from the outer orbits of atoms lying in the surface of the metal. Electrons splashed out in this manner are known as delta rays.

Electrons may also be "brushed out" or released from

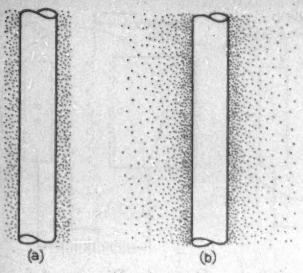

Figure 3. Emission of electrons from a heated body

a few sensitive substances by the impinging of electromagnetic radiations of suitable frequency. The electro-magnetic radiations are light waves, either visible or invisible. This phenomenon of electron removal forms the basis of action in photoelectric cells.

A third method for the removal of electrons from solids is through the application of heat. This method is known by the term thermionic emission and is used in millions of electron tubes of today. The nature of this emission is not difficult to visualize. The electrons are bound to the atoms by their attraction for the nucleus. The electrons are bound to the molecules and to the substance of which they are a part by an attraction called electron affinity and the energy required to remove an electron from a substance is termed the work function. The molecules are in a constant state of agitation while the electrons, in turn, are moving about in the orbits of the atoms. The kinetic agitation of the molecules rises with the temperature and at a sufficiently high temperature the velocity of motion of a few electrons may become great enough to break through the surface of the solid. This escape of the electron is called emission and it may be pictured as in figure 3. Part *a* shows the emission at a relatively low temperature. At the higher temperature a cloud or atmosphere of electrons emanates or evaporates from the hot filament or cathode as shown in part *b*. When the electrons are hurled forth by their kinetic energy, they give to the cathode an image positive charge which exerts a force of attraction. Thus as soon as the electron breaks through the surface, it is attracted back and, barring the presence of other fields and forces, it drops back into the cathode. Electron emission was studied by Richardson who reasoned that it was similar to the phenomenon of evaporation of liquids. Richardson suggested an equation now bearing his name for showing the magnitude of current emitted.

The materials used for cathodes which are satisfactory for electron emission are tungsten, thoriated tungsten, and oxide-coated alloys. Pure tungsten cathodes operate at a high temperature; they are strong and will withstand positive-ion bombardment better than the other emitters. The thoriated-tungsten cathode was developed by Langmuir and his co-workers. It consists of tungsten containing a small amount of thorium oxide. At a suitably high temperature the oxide is reduced to thorium which diffuses through the metal and forms a layer of pure thorium on the surface of the cathode. The thorium layer, one atom thick is the source of electron emission. Wehnelt found that certain oxides when placed on a metal base became excellent emitters at relatively low temperatures. Strontium and barium oxides have proved to be the best. During operation a thin layer of barium forms on the surface of the oxide and this serves as the source of emission of electrons.

Action of Electron Tubes

The value of nearly all electron tubes lies in their property of unilateral conductivity (that is, the ability to conduct current in one direction but not in the other). This property was shown in the "Edison effect" and was the basis of action of the Fleming valve. The reason for this property can be readily understood. Consider two electrodes placed in a tube having a high vacuum as shown in figure 4. Let F represent the cathode which is heated so as to be emitting a copious supply of electrons and P is the anode connected through a battery to the cathode. If the battery is connected so that P is positive with respect to the cathode, as in a, the negatively charged electrons will be attracted toward P and part of them will land on P, thus constituting an electric current through the vacuum. However, if the battery be connected so that P is negative with respect to F, as in part b, it will repel the electrons and no current will pass. Obviously, if an alternating source of potential be substituted for the battery, electrons will pass to P for those loops of voltage when P is positive but will not do so when P is negative. Thus this two-electrode device becomes a rectifier of alternating current. The factors which control the flow of electrons between the cathode and the anode or plate P are not entirely evident on the surface. Thus the number of electrons which pass to P in a tube having a high vacuum depends first on the initial velocity of emission of the electrons which is determined by the temperature of the cathode; second, upon the attraction of the cathode for the electrons; third, upon the attraction of the plate which depends on the plate voltage; and, fourth, upon the space charge. The fourth factor, space charge, is due to the resultant charge in the space surrounding the cathode caused by the presence of the electrons which are being emitted. A cloud of electrons surrounding a cathode may be pictured as in figure 3. Each of these electrons is a negative charge and as such exerts a repulsion on all other electrons in its vicinity. At the instant a particular electron emerges from the cathode, all electrons in space are exerting a repelling force but as it moves away from the cathode all of those behind it are repelling or now aiding it toward the plate. The influence of space

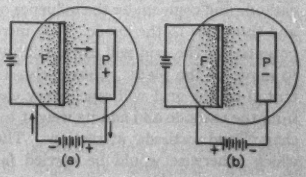

Figure 4. Diagram of two-electrode tube or diode

charge is very effective in a high vacuum and it was once believed that no emission would exist in a perfect vacuum. The two-electrode high-vacuum tube with tungsten filament is used for rectifying high voltages for use in radio transmitting stations, X-ray equipment, smoke eliminators, and wherever a high continuous voltage is desired. The two-electrode vacuum tube is used as a detector in modern radio receiving sets.

The addition of a small amount of gas to a two-electrode tube changes its characteristic action. The presence of the gas permits ionization to occur and the positive and negative ions thus formed pass to the cathode and anode, respectively. The ions serve as carriers of electrons and increase the current slightly but a large increase in current results from another action. Thus the negative ions formed are electrons and are attracted swiftly to the positive anode. The positive ions are atoms (less one or more electrons) and because of their large mass they move relatively slowly. Each positive ion can neutralize the charge on one electron in the space charge at a given instant, but because of its slow motion it serves to neutralize many electrons while in transit. Thus it is possible for a single positive ion to neutralize successively as many as 300 electrons in the space charge. The neutralization of the space charge permits the positive anode to attract many more emitted electrons and thus the current through the tube is greatly increased.

The gas-filled two-electrode tube is inherently a low-voltage device (that is, it has a low voltage drop from cathode to anode). It rectifies much larger currents than the vacuum type and is used for charging storage batteries and similar low-power d-c applications.

Control of Electron Tubes

DeForest added a third electrode known as the grid to the electron tube. In application in the tube, the grid (figure 5) is a screen or wire mesh placed between the emitter or cathode and the anode or plate. The grid functions by means of a change of potential or charge upon its surface. This change of potential on the grid becomes an additional force acting upon the electrons surrounding the cathode and because of its nearness to the cathode exerts a very powerful influence upon the electron stream to the anode. The figure is a cross-sectional view which shows the usual location of the control grid in a three-electrode tube or triode. If a small positive potential be placed upon the grid, it will exert a relatively powerful pull upon all electrons which emerge from the surface of the cathode. This pull will be added to the effect of their initial velocity of emission and will oppose the repelling effect of space charge. The result of this action is that many electrons will move out farther from the cathode and come under the influence of the positive anode and thus pass to the anode. Any increase in the positive potential of the grid will cause still more of the electrons to move to the plate. Conversely, a small negative potential on the grid will repel every electron that emerges from the cathode and add its weight to the effects of space charge and cathode attraction. Thus many electrons which otherwise would be carried far enough by their initial velocity of emission to travel to the plate will now be held in check by the repelling force of the negative grid. It is obvious that a sufficiently negative potential on the grid would bar all electrons from ever reaching the anode. Thus it is apparent that a suitable variation of potential placed on the grid will control accurately the flow of current in the cathode-anode circuit. Since a mere change of potential does not involve any expenditure of power we have the strange phenomenon of controlling a large amount of power without the use of any power. In the actual application of the triode or three-electrode tube, the circuit for the grid does use some small amount of power. The triode thus is inherently an amplifier of alternating currents and as such it finds its greatest application.

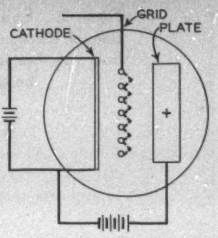

Figure 5. Diagram of three-electrode tube or triode

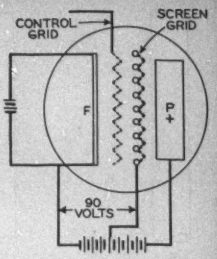

Figure 6. Diagram of four-electrode tube or tetrode

Use of Electron Tubes

Radio signals of telegraph, voice, or television are sent out through space by means of very high-frequency alternating currents called carriers. This method is necessary since lower frequencies will not travel through space very far. The various low-frequency signals to be transmitted are impressed upon the high frequencies by a process of forming, molding, or modulating. At the receiving end of a radio circuit the impressed signals must be demodulated or detected and thus recovered from the high-frequency carrier.

The three-electrode tube or triode is used first as an oscillator in a resonant circuit for producing the high-frequency carrier current. Secondly, this type of tube is used to modulate or mold the low-frequency signal into the high-frequency carrier. In the third place, the triode may be used in the receiver as a detector or remover of the low-frequency signal from the transmitted carrier. Lastly, triodes are used in cascade for amplifying the feeble received signal so that it may be suitable for the desired purpose.

Additional electrodes, usually some type of grid, have been added to the three-electrode tube to increase the range of amplification, to improve the fidelity of amplification, or to prevent oscillations. The heavy loading of a triode by wide fluctuations in the grid potential and the resulting plate current may introduce distortion of the

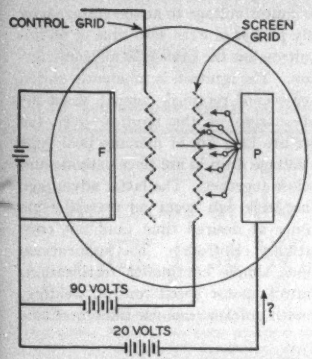

Figure 7 (left). Secondary emission in a tetrode

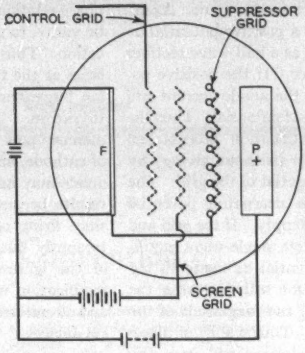

Figure 8 (center). Prevention of secondary emission by fifth electrode in a pentode

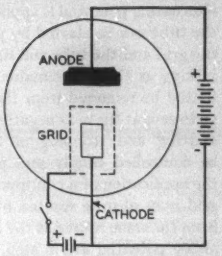

Figure 9. Diagram of a grid-controlled gas-filled rectifier

amplified signal and may produce oscillations because of the feedback of the grid-plate capacitance. To reduce such undesirable results, a fourth electrode known as a screen grid may be introduced between the control grid and the plate, as shown in figure 6. This screen grid is connected to a source giving it a fixed potential somewhat under the normal plate voltage. The screen then serves to establish a fixed potential in space giving a constant attraction upon all emitted electrons regardless of any variation of plate voltage and it greatly reduces the grid-plate capacitance.

A curious phenomenon may result in the use of the screen-grid tube if a low plate voltage be encountered. Thus, at all positive values of plate voltage above 10 to 20 volts, the electrons hitting the plate produce secondary emission (splash out electrons from the plate). In the triode these electrons of secondary emission are attracted back to the plate but in the screen-grid tube for a certain range of low values of plate potential, the splashed-out electrons are attracted back to the screen grid (figure 7). In special cases it is possible for more electrons of secondary emission to go to the screen grid than there are electrons arriving at the plate. Under this condition the plate current will reverse or become negative. Even though the plate current does not reverse, the electrons of secondary emission, which pass to the screen grid, do introduce distortion in the tube when used as an amplifier under the conditions assumed. To prevent this phenomenon, which occurs only under abnormal conditions, a fifth electrode known as a suppressor grid is placed between the screen grid and the plate. This suppressor grid (figure 8) is connected to the cathode or to ground potential. Thus a zero potential is established in the space between the screen grid and the plate. Under these conditions the screen grid has no effect on the electrons splashed out and all return to the plate so that no distortion can be introduced due to this cause. The electron tube containing the five electrodes is called a pentode. It will produce large power outputs with relatively small signal voltages applied to the grid.

Rectifiers

Recently the term mutator has been suggested to cover those forms of electronic devices which are designed for rectifying alternating current for power purposes. The term mutator thus includes grid-controlled hot-cathode rectifiers, mercury-arc rectifiers, and igniter-type mercury-arc rectifiers or ignitrons.

If the vacuum-type triode previously discussed be changed by the addition of gas under low pressure and if the grid be changed so that it completely surrounds the cathode, then a tube possessing some different and desirable properties is obtained. If this tube be connected in the circuit of figure 9, practically no current will flow from the cathode to the anode when the grid is free or not connected to any source of potential. This action is due to the fact that electrons emitted by the cathode land on the grid and make the grid negative. This negative grid repels nearly all electrons and does not permit many to pass through the meshes of the grid to the plate. If the grid is kept negative enough, the electrons cannot attain sufficient velocity to cause ionization and the tube is nonconducting between cathode and anode. As the grid is made less negative a point is reached where the electron velocity is great enough to cause ionization. Positive ions will then form a sheath around the grid and neutralize its effect and a large current flows to the anode. This current is limited only by the impedance of the anode circuit. Once started, the cathode-anode current cannot be stopped by any change of potential on the grid. If the grid circuit is opened, the positive ions will neutralize any electrons which land on the grid, and if the grid be made more negative, it will attract positive ions to its meshes and the resulting positive ion sheath will again neutralize the negative grid so that the cathode-anode current stream will be unaffected. The only way the anode current can be stopped when direct current is applied to the plate is to open the anode circuit.

The hot-cathode grid-controlled gaseous-conductor tube or thyratron finds its usefulness when an

alternating potential is applied to its anode circuit. Again, the tube can be started by placing a positive potential on the grid and the tube will function as a half-wave rectifier as long as the grid remains positive. If the positive potential be removed from the grid, the anode current will go to zero at the next negative wave of potential. Thus the starting and stopping of the rectification process can be controlled simply and perfectly (without arcing) by the application of a continuous potential to the grid. The grid may also be excited by a low alternating potential from the same source as the anode supply. If the grid and anode potential are in step, complete single-wave rectification will occur. If the grid potential be made to lag the anode potential, then rectification will start after the beginning of the cycle and the time and magnitude of the rectified current can be controlled. Thus a shift of phase of the grid voltage through 180 degrees will vary the rectified current from zero to a maximum of half-wave rectification. The thyratron gives fine control of rectified current and finds a wide application in theater stage lighting, flood lighting, motor speed control, and elsewhere.

Mercury-arc rectifiers have been used for rectification for many years. They operate upon the principle of a hot spot upon a mercury-pool cathode maintained by positive-ion bombardment. The arc is started by means of an auxiliary electrode. During recent years mercury-arc rectifiers have been built in large capacities for supplying direct current for electric railway operation. These rectifiers have been built in large steel tanks and use 3, 6, or 12 phases with a corresponding number of electrodes for anodes. For starting the main arc an auxiliary or exciting electrode must be in operation all of the time. The ionization produced by this auxiliary electrode produces conditions favorable for an arc-back or a reversal of the rectified current. Hence the anodes must be very carefully shielded and the arc path must be relatively long.

Quite recently a new method for starting the mercury arc in the rectifier has been invented by Slepian and Ludwig. The device using this new principle is called the ignitron. The ignitron is a mercury-arc rectifier having a third electrode or ignitor which consists of a rod of suitable refractory material which projects through the side of the tube and has a point dipping into the mercury pool. The ignitor electrode serves to fire the arc at will just as the grid of the thyratron may start the gaseous conduction. If the ignitor electrode be made positive with respect to the cathode pool and a suitable critical current be permitted for a few microseconds, a tiny spark occurs between the ignitor and mercury. If the anode potential is positive and of suitable value, this tiny spark expands into an arc which is transferred to the anode through the ionization process previously considered. The arc forms a very low resistance path for the passage of current.

The ignitor principle may be used for a single current surge of half-wave rectification or it may be used for several waves, or for continuous operation. The ignition process must be repeated each time the alternating anode potential becomes positive. The ignitor electrode may be fired from the same a-c source of potential as the anode. Also the phase relation of the ignitor voltage to anode voltage may be varied to give only partial or even zero time of rectification. Thus the ignitron has the same control characteristics as the thyratron. The ignitron is inherently suited for larger current values of rectified current than the thyratron. The advantages of the ignitron over the mercury-pool rectifier are long life of mercury-pool type of cathode, and low voltage drop in arc since cathode and anode may be very close together. The latter advantage results because no arc-back can occur on reverse cycle since firing occurs only at desired time (and not continuously due to auxiliary electrode). The applications of the ignitron include simple continuous rectification, rectification with control, motor speed control, welding, and circuit breaking with quicker response than mechanical devices.

Photoelectric Cells

It was suggested earlier that electrons may be ejected from some solids by the impingement of light rays. It appears that the high-frequency electromagnetic wave (visible or invisible) has the power of imparting energy to the electrons in the outer orbits of atoms of certain photosensitive materials so that these electrons are released or torn from the atom and fly out into space. This phenomenon forms the basis of action of the photoelectric cell or the "electric eye" which is so widely used in many control applications. The more common light sensitive materials are sodium, potassium, barium, strontium, and some of their compounds. The photoelectric cell usually consists of an evacuated tube containing a large area of light-sensitive material and a small anode or wire near the center. The cell is connected into a circuit so that a positive potential is applied to the anode. Whenever light falls on the light-sensitive cathode, electrons are emitted and attracted to the anode. The actual current flowing in the cathode-anode circuit is very small and amounts to only a few microamperes at the best. This small current produces a small voltage drop across a resistance. This potential is amplified by means of other electron tubes to produce a signal for performing the purpose desired. The number of electrons emitted from a light-sensitive surface is directly proportional to the intensity of light falling upon that surface. Thus a variation of light intensity may be transformed into an electric signal to perform a desired purpose. This principle is used in the sound production for the talking picture where a sound track on the film varies the light intensity falling on a photoelectric cell. The photoelectric cell may also be used for picture transmission, for television, and for all kinds of signal applications.

Photoelectric cells may have a high vacuum or may contain gas under low pressure. The emission of electrons by the impingement of light rays is the same in both types. The resulting current to the anode in the vacuum type is equal to the electron emission, but in the gaseous type the current is amplified several times (in practice not exceeding ten times) by the addition of current from the gas ions which are formed during the transit of electrons from the cathode to the anode.

News

Of Institute and Related Activities

Attractions at the AIEE 1938 Winter Convention

A PROGRAM comprised of many attractive features has been arranged for the AIEE 1938 winter convention, which will be held January 24–28 in New York City, with headquarters, as usual, in the Engineering Societies Building, 33 West 39th Street. To provide added interest for the membership the technical program has been enlarged to 16 technical sessions, 1 general session, and 5 conference sessions. This has been made possible without detracting in the least from the usual social functions: the smoker, Edison Medal presentation, dinner-dance, and inspection trips to places of interest. As in previous years, the women's entertainment committee, with Mrs. George Sutherland, chairman, is arranging a special program for the visiting women. For those who would enjoy a few days' vacation after the convention, and in view of the success of last year's cruise, another post-convention cruise to Bermuda has been arranged. A summarized schedule of events is given in an accompanying tabulation.

Edison Medal Presentation

Presentation of the AIEE 1937 Edison Medal to Gano Dunn will take place at a special session of the convention in the engineering auditorium, Wednesday, January 26, at 8:00 p.m. The medal was awarded to Mr. Dunn "for distinguished contributions in extending the science and art of electrical engineering, in the administration of great engineering works, and for inspiring leadership in the profession." A biographical sketch of the recipient is included in the "Personal Items" section of this issue.

General Session

Because of the great interest and importance of current economic problems to engineers, arrangements have been made for an address "Technological Development in Relation to Economics" by H. G. Moulton, president of the Brookings Institution, Washington, D. C. The address will be given at a "general session" scheduled for Wednesday morning, January 26. In order to give all members attending the convention an opportunity to hear Doctor Moulton's address no parallel sessions will be held that morning. It is believed that the women attending the convention will find the subject of interest, and they are cordially invited to attend. A somewhat similar session held during the summer convention at Milwaukee, Wis., last June illustrated the increasing importance of economic problems to the engineer. The program for this session is as follows:

Presiding: W. H. Harrison, president, AIEE

Opening Remarks: President Harrison

Convention Activities: T. F. Barton, chairman, winter convention committee

Presentation of Alfred Noble Prize to G. M. L. Sommerman

Address: Technological Development in Relation to Economics, H. G. Moulton, president, Brookings Institution

Table I. Issues of "Electrical Engineering" Containing 1938 Winter Convention Papers

July 1937	1 paper
September 1937	4 papers
October 1937	3 papers
November 1937	2 papers
December 1937	5 papers
January 1938	11 papers
Subsequent issues	*39 papers

* Advance copies of these papers will be made available at 10¢ each by mail, or 5¢ each if purchased at AIEE headquarters (see order form in advertising section of this issue).

Summarized Schedule of Principal Events

Monday, January 24

9:00 a.m.	Registration
10:00 a.m.	Communication Symposium on modern electric vehicles–I
2:00 p.m.	Symposium on a new carrier telephone system for toll cable Symposium on modern electric vehicles–II Conference on radiation fields

Tuesday, January 25

9:30 a.m.	Lightning protection Symposium on electronics–I Conference on education
2:00 p.m.	Relays and reactors Symposium on electronics–II Conference on sound and vibration
6:30 p.m.	Smoker at the Commodore Hotel

Wednesday, January 26

10:00 a.m.	General session
2:00 p.m.	Instruments and measurements Electric welding Basic sciences
8:00 p.m.	Edison Medal presentation

Thursday, January 27

9:30 a.m.	Power transmission Conference on network analysis and synthesis Electrical Machinery–I Conference on definitions
2:00 p.m.	Television Cables and research Electrical Machinery–II
7:00 p.m.	Dinner-dance at the Plaza Hotel

Friday, January 28

All day	Inspection trips

Saturday, January 29

3:00 p.m.	"Monarch of Bermuda" sails on post-convention cruise to Bermuda

Technical Program

In accordance with the new publication policy, advance copies of papers not published in Electrical Engineering prior to the convention (those listed without publication references, exclusive of addresses) will be available. The price of these advance copies when ordered by mail is 10¢ each; when purchased at headquarters, 5¢ each (see order form in the advertising section of this issue).

The 16 sessions of the tentative technical program announced in Electrical Engineering for December 1937, pages 1516–17, are complete except for subsequent changes made in the sessions on electric vehicles, electrical machinery, and television. The programs for these sessions, as revised, are repeated for convenience.

Symposium on Modern Electric Vehicles

The P.C.C. Street Car, C. F. Hirshfeld, Transit Research Corporation.

Application of Modern Electric Vehicles to Urban Transportation, C. M. Davis, General Electric Company.
January issue, pages 57–60 (Trans.)

Electrical Equipment for Modern Urban Surface Transit Vehicles, S. B. Cooper, Westinghouse Electric & Manufacturing Company.
January issue, pages 50–6 (Trans.)

Results of Operation of P.C.C. Cars in Pittsburgh, Thomas Fitzgerald, Pittsburgh Railways Company.

Modern City Transportation, E. J. McIlraith, Chicago Surface Lines.

Symposium on Modern Electric Vehicles—Continued

Modern Trolley-Coach Operation, Edward Dana, Boston Elevated Railway.
December issue, pages 1461–63

MODERN TROLLEY-COACH OPERATION, **J. H. Polhemus**, Portland Electric Power Company.
December issue, pages 1483–86

OPERATING EXPERIENCE WITH GAS-ELECTRIC AND DIESEL-ELECTRIC BUSES, **R. H. Stier**, Philadelphia Rapid Transit Company.

Address: ELECTRICALLY PROPELLED RUBBER-TIRED HIGHWAY VEHICLES FOR MASS TRANSPORTATION, **Martin Schreiber**, Public Service Co-ordinated Transport.

Electrical Machinery—I

CO-ORDINATION OF POWER TRANSFORMERS FOR STEEP-FRONT IMPULSE WAVES, **V. M. Montsinger**, General Electric Company.

CORONA VOLTAGES OF TYPICAL TRANSFORMER INSULATIONS UNDER OIL, **F. J. Vogel**, Westinghouse Electric & Manufacturing Company.
January issue, pages 34–6 (TRANS.)

A FORMULA FOR THE REACTANCE OF THE INTERLEAVED COMPONENT, **H. B. Dwight** and **L. S. Drung**, Massachusetts Institute of Technology.
November issue, pages 1368–71

Electrical Machinery—II

STRAY-LOAD LOSSES OF D-C MACHINES, **E. W. Schilling**, Michigan College of Mining and Technology, and **R. W. Koopman**, University of Kansas.
December issue, pages 1487–91

D-C MACHINE STRAY-LOAD-LOSS TESTS, **Victor Siegfried**, Worcester Polytechnic Institute.
October issue, pages 1285–89

UNSYMMETRICAL SHORT-CIRCUITS ON WATER-WHEEL GENERATORS UNDER CAPACITIVE LOADING, **C. F. Wagner**, Westinghouse Electric & Manufacturing Company.
November issue, pages 1385–95

OVERVOLTAGES CAUSED BY UNBALANCED SHORT CIRCUITS—EFFECT OF AMORTISSEUR WINDINGS, **Edith Clarke** and **C. Concordia**, General Electric Company, and **C. N. Weygandt**, University of Pennsylvania.

ALTERNATOR SHORT-CIRCUIT CURRENTS UNDER UNSYMMETRICAL TERMINAL CONDITIONS, **A. R. Miller** and **W. S. Weil, Jr.**, Lehigh University.
October issue, pages 1268–76

Television

Address: CURRENT FIELD WORK IN TELEVISION, **Ralph R. Beal**, Radio Corporation of America.

Address: THE COAXIAL CABLE SYSTEM FOR TELEPHONE TRANSMISSION, **M. E. Strieby**, Bell Telephone Laboratories, Inc.

TECHNICAL CONFERENCES

The programs for the technical conferences in so far as they have been made available to date are given here. These conferences are intended to be informal in character. Preprints of the papers will not be available in advance of the convention, although a few prepared papers and prepared discussions may be used at the time of the convention for the purpose of stimulating pertinent discussion from the audience.

Radiation Fields. The following general papers on the physics of radiation are believed to provide a proper background for discussion. The object of the conference is by no means discussion of papers themselves, but fundamentally an exchange of newer ideas and research results on these topics.

ELECTROMAGNETIC RADIATION AND THE IMPEDANCE CONCEPT, **S. A. Schelkunoff**, Bell Telephone Laboratories, Inc.

SOUND PRODUCTION AND COLLECTION (EMPHASIZING ELECTRICAL AND ACOUSTICAL ANALOGIES), **H. F. Olson**, Victor Division, Radio Corporation of America.

ELASTIC WAVES IN SOLIDS AND SURFACE WAVES OF FLUIDS, **H. Poritsky**, General Electric Company.

Sound and Vibration Measurement. This conference will constitute an open meeting on progress in the sound measurement field and related questions. The program tentatively arranged includes the following principal topics:

1. The proposed AIEE Test Code on Apparatus Noise Measurement will be reviewed, including consideration of changes that have been proposed since its publication, with a view toward rendering a final report to the standards committee recommending the publication of the code in pamphlet form.

2. Several speakers will present proposals for the development of noise measurement standards or specifications for particular lines of apparatus, following the general procedure of the AIEE test code. If the interest and the progress shown warrant it, the committee may undertake to organize a formal Institute session on the subject with published papers at the summer convention.

3. There will also be a general discussion of methods of measuring vibration, including the velocity and acceleration, as well as the amplitude of the motion. The desirability of the committee's sponsoring definitions and measurement methods in this field to supplement the work on sound measurement will be considered.

INFORMAL TALKS

EXPERIENCES WITH THE SOUND LEVEL METER STANDARDS, **W. S. Barstow**, American Telephone and Telegraph Company.

EXPERIENCES WITH NOISE SPECIFICATION TESTS, **A. P. Fugill**, The Detroit Edison Company.

VIBRATION MEASUREMENT METHODS, **C. W. LaPierre**, General Electric Company.

Definitions. This conference of the subcommittee on definitions of the AIEE committee on basic sciences will consider the definitions in group 05 of the final revised report of the sectional committee on definitions of electrical terms (*C*-42). According to present arrangements for the conference each member of the subcommittee will present a set of suggested definitions and after each presentation discussion will be invited.

It is planned to invite to the conference all members of the following committees: basic sciences, sectional committee on electric and magnetic magnitudes and units (*C*-61), sectional committee on definitions of electrical terms (*C*-42), subcommittees of the sectional committee on electrical definitions, and other interested persons.

SMOKER

The excellent facilities of the Hotel Commodore again have been made available for the smoker this year. The Grand Ballroom and West Ballroom with its lounge and service bar have been reserved. These facilities together with a good view of an excellent show and supper served by the experienced Commodore staff assure a pleasant evening. Don't miss this opportunity to chat with your friends amidst pleasant surroundings. The seating will be at tables of 10 with ample space to move around. Those planning to attend are urged to send their reservations to the AIEE Smoker Committee, 33 West 39th Street, New York, N. Y., at an early date. All tables will be reserved. Tickets will be $3.50 per person.

DINNER-DANCE

The Grand Ballroom of the Hotel Plaza will be the setting for the outstanding social event of the convention, namely, the annual dinner-dance and buffet supper to be held Thursday evening, January 27. The Plaza, located on Fifth Avenue between 58th and 59th Streets and overlooking Central Park to the north, is known for its sparkling atmosphere and the excellence of its cuisine. Lounging rooms adjacent to the ballroom will be reserved for Institute members and their guests affording spacious and luxurious surroundings for meeting friends and acquaintances.

George Ellner and his orchestra again will provide music during the dinner and later for the dance. As in the past, encores will be limited in order to provide a maximum number of dances during the evening.

In order to start dancing earlier the dinner hour has been advanced as shown in the following schedule:

7:00 p.m.	Dinner
9:30 p.m. to 2:00 a.m.	Dancing
Midnight to 2:00 a.m.	Buffet supper

Tickets will be sold on the following plans:

Dinner and dance	$5.00 per person
Dinner, dance, and buffet supper	6.50 per person
Dance and buffet supper	3.00 per person

To assist the committee, an early pur-

Table II. A Few of the Hotels Available

Hotel	Location	Rooms With Private Bath	
		Single	Double
Astor	Broadway and 44th Street	$3.50– 5.00	$6.00– 8.00
Biltmore	Madison Avenue and 43d Street	6.00–12.00	8.00–14.00
Bristol	129 West 48th Street	2.50– 4.00	3.50– 7.00
Commodore	Lexington Avenue and 42d Street	3.50– 5.00	5.00– 8.00
Edison	228–248 West 47th Street	2.50– 5.00	4.00– 8.00
Governor Clinton	31st Street and 7th Avenue	3.00– 5.00	4.00– 7.00
Lexington	Lexington Avenue and 48th Street	3.50– 5.00	4.50– 7.00
Lincoln	Eighth Avenue and 44th Street	3.00– 4.50	4.00– 6.50
McAlpin	Broadway and 34th Street	3.00– 7.00	4.50– 9.00
Montclair	Lexington Avenue and 49th Street	3.00– 5.00	5.00– 8.00
Murray Hill	Park Avenue and 40th Street	2.50– 4.00	4.00– 6.00
New Yorker	8th Avenue and 34th Street	4.00– 8.00	6.00–10.00
Pennsylvania	7th Avenue and 32d Street	3.50– 6.00	5.00– 9.00
Plaza	Fifth Avenue and 59th Street	7.00–10.00	9.00–14.00
Roosevelt	Madison Avenue and 45th Street	5.00– 9.00	7.00–12.00
Vanderbilt	Park Avenue and 34th Street	3.50– 5.00	6.00– 8.00
Waldorf-Astoria	Park Avenue and 50th Street	7.00–12.00	10.00–15.00

Future AIEE Meetings

Winter Convention
New York, N. Y., Jan. 24–28,1938

North Eastern District Meeting
Lenox, Mass. (Pittsfield Section)
May 18–20, 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., August 9–12, 1938

Southern District Meeting
Miami, Fla., November 1938

chase of tickets is requested. Dinner reservations should include names of guests and desired seating arrangements. Tables will be laid for 8 or 10 places and every effort will be made to satisfy the wishes of those attending. Reservation requests should be sent to the AIEE Dinner-Dance Committee, 33 West 39th Street, New York, N. Y., checks being made payable to "Special Account, AIEE."

Inspection Trips

During the week of the convention a number of interesting inspection trips will be arranged. Some of these will be related to the subjects of technical papers, and others will be of general interest.

The tentative list of inspection trips under consideration is as follows: photo-engraving plant, sponsored radiobroadcast, automobile assembly plant, vehicular tunnel, sewage treatment plant, stainless steel streamlined train, grid-controlled rectifier, high-pressure turbine unit, radio tube manufacturing, Stock Exchange, New York City Fire College, cable manufacturing plant, copper refining plant, Bell Telephone Laboratories, and television studios.

Through the courtesy of the General Electric Company, sponsor of the "Hour of Charm" radio program featuring Phil Spitalny and his all-girl orchestra, a limited number of tickets is expected to be available for the broadcast of that program on Monday evening, January 24. It is suggested that out-of-town members indicate their desire for tickets with their advance registration.

The Bermuda Cruise

Because of the success of last year's cruise, a second post-convention cruise to Bermuda has been arranged. At this popular resort, one may golf on fine courses, fish in waters that yield game fish and strange specimens, bicycle over limestone roads bordered by oleanders and hibiscus, visit the famous caves, ride on spirited horses or in gaily canopied victorias (there are no automobiles in Bermuda), or just sit on the terrace of the hotel and enjoy the beauty of the gardens and the distant landscape.

The cruise party will sail from New York January 29 at 3:00 p.m. and will return February 4 at 9:00 a.m. This will allow practically three days in Bermuda; for those who wish to stay longer, stop-over privileges are available. Rates for the trip depend on the location chosen on the ship, but begin at $85 per person, which includes every necessary expense—first-class round-trip transportation, rooms with bath and all meals both on ship and in Bermuda at the Hotel Bermudiana, all government taxes, and a visit to old St. Georges. It does not include tips or sightseeing expenses, both of which should cost less than $15 total. Those making the earliest reservations will have the greatest opportunity to choose accommodations at the lower rates. Full information may be obtained from Leon V. Arnold, cruise director, 36 Washington Square West, New York, N. Y.

Hotel Rates and Registration

Reservations for hotel accommodations should be made by writing directly to the hotel of your preference. In table II is included a brief list of some of the leading hotels in the vicinity.

Members in near-by Districts should fill in and post promptly the mail registration card included with the mailed announcement of the winter convention. This will permit the committee to have badges ready and prevent congestion at the registration desk upon arrival. There will be a registration fee of $2 for non-members with the exception of Enrolled Students of the Institute, and the immediate families of members.

Winter Convention Committee

The personnel of the 1938 winter convention committee is as follows: T. F. Barton, *chairman*, C. R. Beardsley, O. B. Blackwell, G. E. Dean, A. F. Dixon, E. E. Dorting, H. S. Osborne, C. S. Purnell, George Sutherland, and F. P. West. The chairmen of the subcommittees completing the arrangements are: C. M. Gilt, *dinner-dance;* E. S. Banghart, *smoker;* E. R. Thomas, *inspection trips;* and Mrs. George Sutherland, *women's entertainment.*

Alumni Gatherings

During winter-convention week, the following special gatherings will be held by college alumni organizations.

Columbia Electrical Engineering Alumni, January 24, 6:30 p.m. An informal dinner at $1.50 per plate will be held at the Columbia University Club, 4 West 43d Street. Reservations may be sent to J. W. Balet, 4 Irving Place, New York, N. Y.

Brown Engineering Association, January 26, 12:30 p.m. Informal luncheon will be held at the Hotel Bristol, 129 West 48th Street. Reservations may be sent to A. E. Cuddeback, 36–22 208th Street, Bayside, N. Y.

District 6 Award for Branch Paper

A prize for Branch paper for the academic year ending June 30, 1937, has been awarded by the AIEE North Central District (No. 6) to John K. McKendry (Enrolled Student) for his paper "The Development of Sound Pictures," which was presented at the tenth annual conference of Student Branches in the District held at South Dakota State College, Brookings, April 23–24, 1937. The award was made in accordance with the revised rules governing prizes for AIEE papers recently adopted by the Institute's board of directors (*EE, April '37, p. 492*), which stipulate that prizes for Branch papers shall be awarded on the basis of the academic year, July 1 to June 30, inclusive.

A typical scene in Bermuda

Bonneville Advisers Appointed. The four-man advisory committee that will co-operate with J. D. Ross (A'08, F'12) newly appointed administrator of the Bonneville power development on the Columbia River, has been completed by the action of the various federal departments concerned. The members of the committee will act as liaison officers to keep the administrator in touch with plans of their respective agencies which may affect or be affected by the Bonneville development. The members and the departments they represent are: Frank A. Banks, Department of Interior; Halbert Selby, Department of Agriculture: Thomas M. Robins, War Department; and Roger B. McWhorter, Federal Power Commission.

Committee Appointed for Pacific Coast Convention

Appointment of the 1938 Pacific Coast convention committee by President W. H. Harrison and the approval of the convention dates as August 9 to 12 have set in motion much activity by members of Portland (Ore.) Section in an effort to make the convention, which is to be held in that city, the most successful on record. According to C. B. Carpenter, publicity subcommittee chairman, all subcommittees already are functioning. The date of the convention has been set ahead of the customary date in order that members from other sections of the country more conveniently may combine attendance at the convention with a vacation trip to the Pacific Coast.

E. F. Pearson has been named general chairman of the convention committee; to assist him the following have been appointed: D. F. Smith, *vice-chairman;* Corbett McLean, *secretary;* John Bankus, *treasurer;* Walter Brenton, *meetings and papers;* O. B. Coldwell, *finance;* S. E. Caldwell, *registration;* R. J. Davidson, *hotel arrangements;* V. B. Wilfley, *inspection trips;* C. B. Carpenter, *publicity;* L. R. Elder, *reception;* A. H. Kreul, *entertainment;* J. C. Henkle, *golf;* A. L. Albert, *student activities;* G. E. Bishop, *transportation;* and Mrs. J. F. Spease, *women's entertainment.*

H. G. Moulton to Address Convention General Session

As announced elsewhere in this issue, H. G. Moulton, president, The Brookings Institution, Washington, D. C., will be the principal speaker at the "general" session of the Institute's 1938 winter convention to be held Wednesday morning, January 26. Doctor Moulton's subject will be "Technological Development in Relation to Economics," and his address will follow immediately after the presentation of the Alfred Noble prize to G. M. L. Sommerman (A'31, M'37), which will take place after the opening remarks of President W. H. Harrison and T. F. Barton, general chairman of the winter convention committee.

Doctor Moulton has been a student of political economy for many years. Following his graduation from the University of Chicago in 1907 with the degree of bachelor of philosophy, he engaged in a teaching career, becoming a fellow in political economy at the University of Chicago in 1909, and advancing to full professorship at that institution in 1922. He was granted a degree of doctor of philosophy from the University of Chicago in 1914. In 1922 he became director of the Institute of Economics at Washington, D. C. This body was amalgamated with the Institute for Government Research and the Robert Brookings Graduate School of Economics and Government in 1928 to form the Brookings Institution, and Doctor Moulton has been president of that organization since that time.

Doctor Moulton is a fellow of the American Association for the Advancement of Science (vice-president, 1936) and a member of the American Academy of Arts and Sciences. He is author of a number of books on political and economic issues, and has delivered many lectures on those subjects. In April 1937 he gave the Eleventh Steinmetz Memorial Lecture entitled "Engineering Progress and Economic Progress"

H. G. Moulton

before the AIEE Schenectady Section (*EE, May '37, p. 510–17*). He has received the honorary degree of doctor of laws from several institutions.

This "general" session is the second of its type to be sponsored by the AIEE, the first having been held during the Institute's 1937 summer convention at Milwaukee, Wis. Arrangements for the session were made by a special committee appointed by Chairman H. S. Osborne of the technical program committee and consists of H. S. Bennion, C. R. Beardsley, L. W. W. Morrow, Mr. Osborne, and W. E. Wickenden.

Executive Committee Meets at Institute Headquarters

A meeting of the executive committee of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., December 15, 1937, in place of the regular meeting of the board of directors.

Present: W. H. Harrison, *chairman,* O. B. Blackwell, F. M. Farmer, A. M. MacCutcheon, W. I. Slichter, members of the committee; C. R. Beardsley, member of the board of directors; National Secretary H. H. Henline.

Recommendations adopted by the board of examiners at a meeting held November 18, 1937, were reported and approved. Upon recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 1 applicant was elected to the grade of Fellow; 29 applicants were transferred, 15 were elected, and 1 was reinstated to the grade of Member; 130 applicants were elected to the grade of Associate; 853 Students were enrolled.

Approval was given to monthly disbursements, reported by the finance committee, amounting to $19,571.43 in November and $19,695.09 in December.

Announcement was made of the award by the Edison Medal Committee, on December 10, of the 1937 Edison Medal to Gano Dunn.

Appointments of Institute representatives, recommended by the standards committee, were reported and confirmed, as follows. Frank B. Powers as chairman of the sectional committee on railway motors —*C35*, and L. C. Ilsley as Institute representative on the mining standardization correlating committee; and confirmation was given to the approval by the standards committee of the naming of William Seubert as chairman of the sectional committee on industrial control—*C19*, of which the National Electrical Manufacturers Association and AIEE are joint sponsors.

W. C. Wagner was appointed AIEE representative on the committee on low voltage hazards of the American Society of Safety Engineers, the engineering section of the National Safety Council, for the administrative year ending July 31, 1938.

Upon recommendation of the executive committee of the Pittsburgh Section, Vice-President I. Melville Stein of the Middle Eastern District, and the chairmen of the finance and Sections committees, authority was granted for the addition of Centre, Clearfield, and Jefferson Counties, Pennsylvania, to the territory of the Pittsburgh Section.

An invitation from The Institution of Engineers, Australia, to the AIEE to appoint an official representative to attend the annual engineering conference of The Institution, at Sydney, N.S.W., during the week of March 28, 1938, in connection with Australia's 150th anniversary celebration, was referred to the national secretary with power.

It was decided that the January 1938 meeting of the board of directors would be held Wednesday afternoon, January 26, during the winter-convention week.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

World Radio Convention. The Institution of Radio Engineers (Australia) is organizing a world radio convention to be held at Sydney, April 4–14, 1938. This is believed to be the first world radio convention ever held anywhere to discuss all phases of radio engineering, embracing all persons interested in radio; technical subjects include wave propagation, telecommunication, broadcast transmission and receivers, sound projection, electromedical, and television. Prominent engineers from all parts of the world are expected to attend. The convention is being held during the celebration of the 150th anniversary of the foundation of Australia. All interested persons are invited to communicate with the convention secretary, O. S. Mingay, 30 Carrington Street, Sydney.

AWS Officers for 1938. Election of the following new officers of the American Welding Society for 1938 was announced at the recent annual meeting of the society: *President*—P. G. Lang, Jr., engineer of bridges, Baltimore and Ohio Railroad, Baltimore, Md.; *Senior Vice-President*—

Membership—

Mr. Institute Member:

The returns from this year's "round robin," in which we asked for your co-operation in obtaining additional members, have been coming in steadily. The recommendations contained in them are extremely helpful to us and you are urged to send yours along, if you have not already done so.

We would like you to think of possible prospects within your knowledge who are eligible, though not at present members, and who might be interested in joining the Institute. Send their names and addresses to your Membership Committeeman now while the busy season is in the making.

If you will perform this service at the expense of a small amount of your time, your local membership officer will do the rest. Together we can render a valuable service, both to the Institute and to the new members whom we enroll.

Thank you.

J. Elliot Du Cornwall

Vice-Chairman, District No. 3
National Membership Committee

G. F. Jenks, chief of technical staff, Office of Chief of Ordnance, United States Army, Washington, D. C.; *Divisional Vice-Presidents*—K. V. King, Standard Oil Company of California, San Francisco, and W. J. Sanneman, Tennessee Coal, Iron & Railroad Company, Birmingham, Ala.; *Directors at large*—A. M. Candy (A'15, M'20) Hollup Corporation, Chicago, Ill.; J. H. Deppeler, Metal & Thermit Corporation, New York, N. Y.; E. R. Fish, The Hartford Steam Boiler Inspection and Insurance Co., Hartford, Conn.; A. E. Gaynor, J. A. Roebling's Sons Co., New York, N. Y.; L. S. Moisseiff, consulting engineer, New York, N. Y.

Cash Prizes for Papers Partially Restored

Provision in the Institute's 1937–38 budget has been made for cash awards to accompany the national and District prizes for initial and Branch papers to be awarded during the current year. In recent years, no prizes have been accompanied by cash awards except the District prizes for Branch papers.

All technical papers presented before the Institute during the year are eligible under the AIEE paper prize regulations for competitive consideration for one or more of the established prizes, regardless of whether presented before a Branch meeting, a Section meeting, a District meeting, or a national convention, the several classes providing for equitable competition. With the exception of the prizes for Branch papers, both District and national prizes are awarded each spring for papers presented during the preceding calendar year. For Branch papers, both national and District prizes are awarded on the basis of the academic year, July 1 to June 30, inclusive. Suitable certificates accompany all awards.

National prizes that may be awarded annually, and those to be accompanied by cash awards during the current year, are as follows:

1. Best paper prizes:
   Engineering practice
   Theory and research
   Public relations and education
2. Prize for initial paper ($100)
3. Prize for Branch paper ($100)

District prizes that may be awarded annually, together with the cash awards provided for the current year, are:

1. Prize for best paper
2. Prize for initial paper ($25)
3. Prize for Branch paper ($25)
4. Prize for graduate student paper

Although all papers presented are *eligible*, there is no provision for automatic consideration of papers, except that those approved by the technical program committee and presented at national conventions or District meetings will be considered by the national prize committee for the national "best paper" and the "initial paper" prizes without being offered formally for competition. All other papers for which prize consideration is desired must be *submitted* specifically for that purpose, through the District secretary for District prizes, or through the national secretary's office for the national prizes.

Deadline Dates

Papers to be considered for 1937 national prizes must be submitted not later than February 15, 1938. Papers to be considered for the District "best" and "initial" paper prizes must be submitted on or before February 15, 1938; for the District, Branch and graduate student paper prizes, before July 15, 1938 (for papers presented during the academic year ending June 30, 1938). Those wishing further information may obtain a booklet entitled "National and District Prizes" by writing to AIEE Headquarters, 33 West 39th Street, New York, N. Y.

Broadcast Engineering Conference. The department of electrical engineering of The Ohio State University, Columbus, is sponsoring a conference or short course on broadcast engineering during the period February 7–18, 1938. The purpose is to bring together leaders in the industry and practicing engineers from all parts of the United States and Canada in a discussion of some of the most important technical problems. Sessions will consist of a formal lecture by the leader, followed by round-table discussion. Registration will be limited. Speakers at the various sessions and their subjects are as follows:

H. H. Beverage (A'23, M'34) chief research engineer, R.C.A. Communications, Inc.—ultrahigh frequency propagation.

G. H. Brown, member of firm, Godley and Brown, consulting engineers—broadcast antenna design.

J. F. Byrne (A'32) engineer, Collins Radio Company—field strength surveys.

J. H. Dellinger, chief of radio section, National Bureau of Standards—propagation of broadcast frequencies at night.

W. H. Doherty, radio development department, Bell Telephone Laboratories, Inc.—high-power radio-frequency amplifiers.

W. L. Everitt (A'25, F'36) professor of electrical engineering, The Ohio State University—coupling networks.

H. M. Hucke, chief communications engineer, United Airlines Transport Corporation—snow static effects on aircraft.

G. M. Nixon (A'28) development engineer, National Broadcasting Company—studio acoustics.

Harold L. Olesen (M'27) assistant general sales manager, Weston Electrical Instrument Corporation—indicating instruments.

P. C. Sandretto, communications engineer, United Airlines Transport Corporation—some principles in aeronautical ground radio station design.

A. E. Thiessen, commercial engineering manager, General Radio Company—modulation and distortion measurements.

Perkin Medal Awarded. The Perkin Medal of the Society of Chemical Industry has been awarded to F. J. Tone, president of The Carborundum Company, Niagara Falls, N. Y., and will be presented to him at a joint meeting of the American section of that society and the American Chemical Society, January 7, 1938. The medal is awarded annually for the most valuable work in applied chemistry, and is given to Doctor Tone for his work in the field of abrasives and refractories.

AIEE Officers to Be Nominated Soon

In accordance with the Institute's by-laws, the national nominating committee of the AIEE will meet during the winter convention to be held in New York, N. Y., January 24–28, 1938, for the purpose of nominating national officers to be voted upon by the membership in the spring of 1938. Members of this year's national nominating committee are as follows:

Representing the Board of Directors

C. R. Beardsley, Brooklyn Edison Company, Brooklyn, N. Y.

O. B. Blackwell, Bell Telephone Laboratories, Inc., New York, N. Y.

Vannevar Bush, Massachusetts Institute of Technology, Cambridge

R. W. Sorensen, California Institute of Technology, Pasadena

A. C. Stevens, General Electric Company, Schenectady, N. Y.

C. R. Jones, *alternate*, Westinghouse Electric & Manufacturing Co., New York, N. Y.

Representing the Ten Geographical Districts

1—W. H. Timbie, Massachusetts Institute of Technology, Cambridge

2—J. H. Lampe, Johns Hopkins University, Baltimore, Md.

3—R. H. Tapscott, Consolidated Edison Company of New York, Inc., New York, N. Y.

4—Mark Eldredge, Memphis Power and Light Company, Memphis, Tenn.

5—W. T. Ryan, University of Minnesota, Minneapolis

6—L. N. McClellan, United States Bureau of Reclamation, Denver, Colo.

7—A. L. Maillard, Kansas City Power and Light Company, Kansas City, Mo.

8—F. B. Doolittle, Southern California Edison Company, Ltd., Los Angeles

9—E. F. Pearson, Northwestern Electric Company, Portland, Ore.

10—M. J. McHenry, Canadian General Electric Company, Ltd., Toronto, Ontario

Provisions of the AIEE constitution and by-laws relating to nominations were given in ELECTRICAL ENGINEERING for November 1937, page 1415. In addition to those to be designated by the national nominating committee, nominations also may be made independently. Briefly, independent nominations may be made by a petition of 25 or more members sent to the national secretary at Institute headquarters, not later than March 25, to be placed before the nominating committee for inclusion in the ballot of such candidates as are eligible. Petitions for the nomination of vice-president may be signed only by members within the District concerned.

Course in Building Illumination. Beginning early in February 1938, an evening course in illumination of buildings will be given at Columbia University, New York, N. Y., under joint sponsorship of the school of architecture and the department of electrical engineering. Although specially intended for architects and designers, the course contains much of value and interest to those connected in other ways with lighting. The course will be conducted by A. L. Powell (A'13, F'26) supervising engineer, Atlantic division, incandescent lamp department, General Electric Company, New York, N. Y., and past chairman of the AIEE committee on production and application of light. Other lecturers will include: Lillian E. Eddy, L. J. Buttolph (M'36), R. E. Clisdell, T. C. Lindholm, R. G. Morison, and K. Staley.

Business Manager for "EE" Appointed

At the suggestion of the AIEE publication committee, F. A. Norris, office manager at Institute headquarters, has been appointed business manager of ELECTRICAL ENGINEERING. In this capacity, Mr. Norris will be responsible for all business matters pertaining to the Institute's publications. In his capacity as office manager, he has handled many of these matters for some years, so that his new appointment represents primarily a recognition of his services to the Institute's publications.

F. A. Norris

Mr. Norris has been associated with the AIEE headquarters staff since 1904, when he entered the business world. Appointed officer manager in 1913, he has been intimately associated with practically every phase of Institute activities during the past 25 years. A large part of the voluminous correspondence with members, with the officers of Institute Sections and Branches, and with Institute committees generally has been handled across his desk. Other important duties include the supervision of Institute accounts, the maintenance of all membership records, and the issuance of the AIEE Year Book. Of especial importance has been his long responsibility for the preparation and administration of the Institute's annual budgets.

Eta Kappa Nu Announces 1937 Awards

Chauncey Guy Suits of the research laboratory of the General Electric Company, Schenectady, N. Y., has been selected by Eta Kappa Nu, honorary electrical engineering society, as the outstanding young American electrical engineer for 1937. Doctor Suits was chosen from 60 candidates nominated from every section of the country, and becomes the second man to receive this honor. [In 1936, Frank M. Starr (A'30, M'37) also of the General Electric Company, received the first award to be made.] Three honorable-mention awards for 1937 also have been made to: Leonard L. Carter (A'29, M'35) assistant chief engineer of the Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.; Philo T. Farnsworth, president of Farnsworth Television, Inc., Philadelphia, Pa.; and Clifford A. Faust (A'35) of the advertising department of the Ohio Brass Company, Mansfield.

The awards were made by a committee of seven prominent engineers, five of whom were not members of Eta Kappa Nu: Vannevar Bush (A'15, F'24, director), Massachusetts Institute of Technology, Cambridge; H. P. Hammond, Pennsylvania State College, State College; A. M. Dudley (A'08, F'13), marine electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; T. F. Barton (A'12, F'30), district engineer, General Electric Company, New York, N. Y.; and H. H. Beverage (A'23, M'34) of the Radio Corporation of America, Riverhead, N. Y. The other two members were John W. Weigt (A'19, M'26), Electric Storage Battery Company, New York, N. Y., and Merle C. Hale, General Motors Corporation, New York, N. Y., both past national officers of Eta Kappa Nu.

The Eta Kappa Nu Award for young engineers who have been graduated not more than ten years and who are not yet 35 years of age was inaugurated two years ago to assure their recognition for "meritorious service in the interests of their fellowmen," and provide examples for newly graduating electrical engineers of what they might expect to attain within ten years through an alert and industrious development of their opportunities. Since an engineering education is presumed to prepare a man for a wide variety of achievements, an attempt is made by the committee of judges to appraise all of a man's activities—technical, civic, social, and cultural—in making the final selections.

Nominations of candidates for the 1937 awards were received from heads of electrical-engineering departments of American colleges, from sections of the AIEE, and individual members and chapters of Eta Kappa Nu. Doctor Suits' name will be engraved on the large bronze bowl permanently displayed at AIEE headquarters in the Engineering Societies Building in New York City. He will be presented with a small bronze replica of this bowl at the citation dinner to be held in New York during the week of the AIEE winter convention, January 24–28, 1938, and the honorable mention recipients will receive appropriate certificates on the same occasion.

ASTM Standards on Insulating Materials. The 1937 compilation of "ASTM Standards on Electrical Insulating Materials" has been issued by the American Society for Testing Materials. In addition to the current report of ASTM committee *D-9* on electrical insulating materials, this 373-

page publication includes all of the 37 ASTM specifications and test methods covering the various types of insulating materials. In addition, there are two proposed standards covering tests for neutralization number of petroleum products and specifications for rubber insulating blankets. Of particular interest in the edition are the three discussions on significance of tests involving dielectric strength tests, resistivity tests, and impact tests, prepared by three prominent technologists. Copies can be obtained from ASTM Headquarters, 260 South Broad Street, Philadelphia, Pa., at two dollars each in heavy paper cover, with special prices on orders for ten or more copies.

Commercial Laboratories Form an Association

Representatives of 20 of the principal commercial laboratories of the United States, at a recent meeting in Chicago, Ill., completed the organization of the American Council of Commercial Laboratories. One of the purposes of the council will be the promotion of the proper use of scientific testing methods for the protection and certification of quality in advertised goods.

In behalf of the council it is stated that the members have been and will be carefully selected to include only organizations to which producers, retailers, and consumers may look for unbiased determinations of quality. Engaging in research and testing for fees, these independent laboratories ascertain and report facts for clients and are unin:fluenced by any ulterior consideration. Laboratories which are adjuncts of other enterprises, or which are not self-supporting, or which for any reason are not independent, are ineligible for membership in this council.

The following officers and members of an executive committee were elected to serve during 1938: P. S. Millar (A'03, M'13) Electrical Testing Laboratories, New York, N. Y., *president;* M. L. Patzig, Patzig Testing Laboratories, Des Moines, Iowa, *vice-president;* D. E. Douty, United States Testing Company, Hoboken, N. J., *secretary;* and A. R. Ellis, Pittsburgh Testing Laboratory, Pittsburgh, Pa., *treasurer;* J. H. Herron (M'35) The James H. Herron Company, Cleveland, Ohio; F. B. Porter, Southwestern Laboratories, Fort Worth, Texas; and T. A. Wright, Lucius Pitkin Inc., New York, N. Y., executive committee.

Wear of Metals. A "Symposium on Wear of Metals" has been published by the American Society for Testing Materials, and is comprised of six technical papers and related discussions that were presented at a recent meeting of the society. Subjects include considerations involved in the wear testing of metals, wear testing of cast iron, wear of metals from the automotive, power equipment, and railroad viewpoints; and wear of metals in the textile industry. Copies can be obtained from ASTM headquarters, 260 South Broad Street, Philadelphia, Pa., at $1.25 each.

New Antenna for KDKA Extends Service Area

The primary service area of KDKA, pioneer radiobroadcasting station, is said to have been increased tenfold by a 710-foot radiator recently erected at Saxonburg, near Pittsburgh, Pa. The 60-ton mast is composed of 32 three-cornered welded steel sections, five feet wide, bolted together and held upright by insulated guy wires attached at the 270-foot and 526-foot levels. The bottom section rests on a porcelain insulator, and other insulators are inserted to break the antenna, electr cally, at the 336-foot level.

A circle of eight 90-foot antennas which are designed to suppress, by out-of-phase radiation, high-angle radiation from the main antenna which they surround, extends the fading zone to greater distances from

the station. The high-angle radiation, or sky wave, causes fading by interference with the ground wave upon which the primary service area depends. The radiator operates at three-quarters wave length, but by the method of feeding radio frequency power to the tower, the current is maintained in phase throughout the entire length.

Cincinnati Section Organizes Study Group

A study discussion group has been established by the AIEE Cincinnati Section with the considered objective, as developed and adopted at its first meeting, of: "The adjustment of the engineer to present-day social conditions, to the end that he may be of the greatest service to the community, state, and nation." The group meets once a month, and its meetings are open to all members of the Section.

At the initial meetings, articles on social and economic subjects that have appeared in recent issues of ELECTRICAL ENGINEERING have constituted the principal subjects discussed. No fees of any kind are required, but members intending to join are expected to study the discussion material and be prepared to take part in the discussion. The steering committee consists of J. A. Noertker, C. D. Coy, E. F. Nuezel, V. G. Rettig, and C. F. Lee.

Standards Association Holds Annual Meeting

Completing its 19th year of service as national standardizing agency, the American Standards Association at its annual meeting held recently in New York, N. Y., reported the largest increase in membership of any year since the association was formed. A total of 16 national groups have become affiliated during the past year, including several in the building field, two in the automotive industry, and the National Retail Dry Goods Association with 5,800 store members, which is the first retailing group to become affiliated.

During the year, 59 standards have been approved, which increases to 382 the number of American standards adopted since the association was organized in 1918 to act as a clearing house for the many standardization activities of trade associations, technical societies, and government bureaus in the United States. Among the more significant electrical standards approved during 1937 were revisions of the National Electrical Code and of the Elevator Safety Code incorporating many new provisions for safe practices in elevator design and operation made as the result of research carried on at the National Bureau of Standards for the elevator industry.

In connection with its international work, the association has been invited to fill a vacancy on the council of the International Standards Association; P. G. Agnew, ASA secretary, was appointed the official ASA representative. Through the association, business interests in this country are participating in several international standardization projects. The adoption last year of the standard developed by the American Society of Motion Picture Engineers as world standard, the international standardization of bearings, the inch-millimeter conversion tables, already have pointed the way to what can be accomplished through co-operation with the other industrial countries of the world.

Following a luncheon, Frank B. Jewett (A'03, F'12, past-president), vice-president, Bell Telephone Laboratories, spoke on "Thirty Years of Standardization in Retrospect." Officers elected for 1938 are:

President—D. D. Barnum (re-elected). Mr. Barnum is a past-president of the American Gas Association and has served on the Board of ASA since 1933.

Vice-President—E. A. Prentis, vice-president, Spencer, White and Prentis, New York, N. Y. (re-elected).

Chairman, Standards Council—F. M. Farmer (A'02, F'13, director) vice-president, Electrical Testing Laboratories, New York, N. Y. (re-elected).

Vice-Chairman, Standards Council—R. P. Anderson, secretary, division of refining, American Petroleum Institute, New York, N. Y.

Business Paper Publisher Dead. Nelson W. Gage, chairman of the board of The Gage Publishing Company, New York, N. Y., died October 5, 1937, at the family homestead, Delanson, N. Y., after an illness of short duration. A native of Knox, Albany County, N. Y., where he was born in 1864, Mr. Gage, after attending Union College, came to New York as a young man where he was first employed in various capacities in the then struggling business publication field. In 1892 he founded his own company of which he was president until 1931 when he retired from active participation in its management. The Gage Company at one time published *Electrical Record* and at present publishes *Electrical Manufacturing*.

Current Items From American Engineering Council

Federal, State, and Local Planning

Operational planning of public enterprise is becoming universal in the United States according to the annual report of the National Resources Committee released November 10, 1937, and it is indicated that serious efforts now are being made to determine the "strategies of civilizations" and to provide national social and economic policies for present and future generations. However, many engineers most experienced in planning operations question the value of national planning which involves the determination of a pattern of living for future generations.

In reviewing its efforts to stimulate planning and to encourage decentralization of planning activities, the National Resources Committee has pointed out that, in addition to the 46 state planning boards, there are now approximately 400 county planning agencies and more than 1,700 similar groups in towns and cities. The committee predicts that state planning boards will increase their resources and usefulness through closer co-operation with other planning bodies, and expand their activities as state legislatures increase planning appropriations. Of the 1,700 municipal planning or zoning agencies, some 1,200 have continuous planning boards for making adjustments in zoning ordinances and for initiating plans for physical improvements including public buildings, parks, thoroughfares and the better use of available resources.

Secretary Ickes, in his letter to President Roosevelt transmitting this Report, states that "continuous planning is needed for the conservation and wise development of our national resources—both natural and human. With new inventions, new ideals, and new discoveries, no fixed plan or policy will suffice, for any rigid mold or blueprint plan, if strictly adhered to, may restrict our freedom rather than enlarge it. If we adopt as our constant objective to hand down to our children an unimpaired physical inheritance in the natural wealth of this continent, then we must make new plans to meet new conditions."

Many engineers are likely to welcome the philosophy that "no fixed plan or policy will suffice," and most of us will agree that any effort to mold our future may "restrict our freedom rather than enlarge it." Member societies should congratulate Secretary Ickes and encourage him to have that principle firmly established as the guiding influence for the National Resources Committee and all its subcommittees. In that way, engineers and engineering organizations may be constructive in their efforts to prevent the enforcement of misguided attempts to predetermine an exact plan of social and economic life for unborn generations to our citizens.

On the subject of regional planning, the National Resources Committee says that "there have always been interstate problems, and we have always had to use some kind of negotiation or planning to meet the critical situations as they arise. It is, therefore, nothing new to have interstate compact commissions and planning agencies studying alternative methods of solution for pressing problems which involve more than one state." The Report then proceeds to name a number of regional planning activities and "demonstration projects" in the Central Northwest, New England, the Ohio Valley, and the Pacific Northwest where it is said that real progress is being made on such problems as flood control, reclamation work, and power policy. A limited number of copies of the report are available from the National Resources Committee, Interior Building, Washington, D. C.

Congress— Special and Regular Sessions

Engineers and engineering societies seem to be particularly interested in the special and regular sessions of this Congress, and for that reason they may wish to know what Washington expects to see Congress do about some of its major issues. No one dares say what will be done, because obviously there are certain to be numerous changes in attitude; but all observers agree that, even at the beginning of a minor campaign year, there are unusually encouraging indications of more independence in thought and action.

The special session is referred to by some as "a brush cutting" session, in which may be seen a number of strategic maneuvers by the Administration to free legislation which is now tightly locked in committees, while the more courageous independent thinkers are fortifying themselves against pressures which heretofore have forced them to vote against their better judgment and wishes.

The Black-Connery Wage-Hours Bill, locked up in the rules committee of the House, is faced with an increasing demand for sweeping revisions even though it passed the Senate last session. Opposition seems even stronger now from all parts of the United States. Representative Lamneck of Ohio has enlisted both southern and western support for a substitute measure which would put the Federal Trade Commission in control and give the states greater control over maximum hours and minimum wages. Secretary of Labor Perkins is also reported to be actively preparing to propose changes as soon as the present bill is out of the rules committee. Organized labor is expected to demand that the powers of the proposed labor Standards Board be reduced before enactment of such far-reaching legislation.

Senator Byrnes of South Carolina is scheduled to lead a real fight for an omnibus reorganization bill, but powerful opposition by Senator Byrd of Virginia makes early passage questionable. Members of the House already have four bills for government reorganization, and it is common knowledge that many influential members of both Houses oppose giving any president all the power proposed by Senator Byrnes. The Division of opinion and the unwillingness of Congress to "clip the wings of the comptroller general" or otherwise surrender control of administrative functions to the White House are estimated to be strong enough to delay action and possibly defeat the major portion of the reorganization program.

The TVA regional planning ideas, although covered by separate legislation, are being discussed in connection with government reorganization. At the last session, the Senate agricultural committee and the House rivers and harbors committee held incomplete hearings on Norris S. 2555, Mansfield H. R.7365 and Rankin H.R. 7863. Every one of these bills is labeled conservation, but in reality they involve public power development and carry far-reaching social implications. At the close of last session, committee leaders indicated that further hearings would be unnecessary, but heightened interest by opposition within Congress to the legislation is said to be responsible for the announcement that hearings on the Mansfield Bill, at least, will be resumed. In a few words, the "Little TVA's" face anything but unanimity of approach to the problem of regional planning for conservation.

Under the guidance of Chairman Byrnes of South Carolina, a special senate committee is to investigate the unemployment and relief situation. Several executives from the Works Progress Administration are handling the work for the committee. It is expected that there will be extended hearings during which engineers and other professional and business groups will be invited to express themselves regarding permanent relief from our unemployment difficulties. In the meantime, Harry L. Hopkins and his associates are preparing for an increase in unemployment and relief expenditures. They are proceeding cautiously because Congress is reported to be less impulsive about reopening the relief coffers, even to

satisfy the less responsible elements of their respective constituencies.

A sudden awakening to the fact that we are not out of "the depression is disturbing Congress as well as the President and his Administration. Curtailed production and increasing unemployment coming parallel with the cessation of "pump-priming" activities are presenting problems ladened with serious implications. The stock market crash is the more visible of the major difficulties, but fundamental economic disturbances must be dealt with more effectively by Congress, the Administration and courageous citizens in both public and private life, without too much watchful waiting and hopeful wishing, to avoid a repetition of the disastrous experiences of the early thirties.

Congress responded to the call for the special session with a new appetite for factual information which evidences serious intention to act with more deliberation with reference to new legislation and large appropriations. Such a disposition is reflected in the number and importance of requests received by AEC for expressions of considered engineering opinion and engineers' interpretation of the implications of proposed legislation.

All questions of major importance are referred to Council's committees whenever there is sufficient time for such action. On short notice, the staff responds with the accumulated expressions of opinion from member societies and their representatives. Council, therefore, urges all affiliated engineering organizations to discuss the major issues in local as well as nation-wide application and asks that they record their conclusions and wishes with the AEC office for staff and committee guidance. Such expressions may be entirely informal, but resolutions are usually more effective. In fact, all actions taken by member organizations or their boards of direction which have a bearing upon public questions, are sought as a background for Council's performance.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Tensor Analysis in Electrical Engineering

To the Editor:

In a recent address delivered October 30, 1937, before the American Mathematical Society entitled "The Application of Tensor Analysis to Problems of Electrical Engineering," Professor D. J. Struik finds certain aspects of circuit theory to be at variance with what I have found them to be in my discussion of "tensors" in ELECTRICAL ENGINEERING for May 1937, page 615. It seems desirable, therefore, to support a statement there made by me with a more detailed argument. The statement in question was to the effect that no substitution of one set of variables (currents) for another will carry one electrical net over into another.

Professor Struik came to the opposite conclusion and stated that, in particular, a rather simple transformation of the variables mentioned carries a delta connection over into a star connection. I have been unable to verify the example given and believe such transformations do not exist.

It is true that the imposition of Kirchhoff constraints on a previously unconstrained system can be interpreted as a net-to-net transformation (the first net being thought of as n separate loops, the second being the connected system) but net-to-net transformations of a more general kind are not thereby implied. The existence of this apparent net-to-net transformation is quite exceptional and can be explained when a complete correspondence is set up between the purely dynamical aspect of the system and the network graph. This I have done in a paper to be found in abstract form in the November number of the *Bulletin* of the American Mathematical Society and which may be summarized as follows.

Terminology used here will be that of Foster (AIEE TRANS., volume 51, 1932, page 309) and Tucker (ELECTRICAL ENGINEERING, volume 56, 1937, page 619). As is well known, a vertex corresponds to a constraint; but the rank of the incidence matrix being one less than the number of vertices, one vertex always represents a redundant constraint. By specializing one vertex and making it a *ground-point*, a one-to-one correspondence between the remaining vertices and the independent constraints becomes possible.

Every net implies its *extended graph* formed when all (independent) vertices are connected to the ground-point by *Lagrangean connections* with which are associated the forces of constraint in the same way that the external forces are associated with the various branches of the net proper.

The extended graph has $n + c$ branches (that is, line segments) where c is the number of constraints. Hence exactly n independent circuits exist and these can be so chosen that each circuit lies outside the net proper except, in each case, for one segment in, and characterizing, each circuit. Hence we can say, with the extended graph in mind, that all branch currents are circuital.

Transformations from one system of currents to another are not interpretable in terms of a new graph, that is, Tucker's transformed incidence matrix will not make sense in general. Linear transformations with coefficients rational numbers may be taken as defining new and more complicated circuital paths in the net but do not imply a new graph. All co-ordinate systems are not on a parity, as the use of tensor notation might suggest, for the system that one naturally picks is the simplest.

The diagonal incidence matrix obtained by Tucker associates a potential difference with each branch but does not show what external forces act on the new variables. The proposed viewpoint does both of these things since the potentials with respect to ground of the vertices can be computed from the forces of constraint.

It would thus appear that the application of tensor analysis to the theory of electrical machines and circuits is still obscure.

Yours truly,

W. H. INGRAM

New York, N. Y.

Graphical Solution of Impedances in Parallel

To the Editor:

In the October 1937 number of ELECTRICAL ENGINEERING (page 1327) I notice that E. C. Goodale gives a graphical method of finding the impedance of two similar impedances in parallel. This method is limited

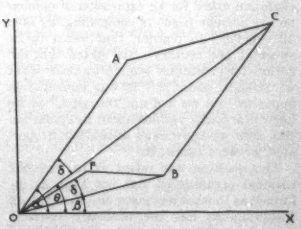

Figure 1

to impedances which can be designated by vectors having the same angle. The following is a method whereby the impedance of any two impedances in parallel may be solved graphically.

Let $A \angle \alpha$ and $B \angle \beta$ be the vector representation of any two impedances.

Draw OA and OB representing $A \angle \alpha$ and $B \angle \beta$ respectively, that is, the length of OA represents to a suitable scale the magnitudes of the vector $A \angle \alpha$ and the $\angle AOX = \angle \alpha$ and $\angle BOX = \angle \beta$. See figure 1.

Complete the parallelogram giving OC = resultant of OA and OB in series.

Upon the base OB construct the triangle OFB similar to triangle OAC.

Then $\angle FOB = \angle AOC$ and $\angle FBO = \angle ACO$.

Then vector OF represents in magnitude

and angle the impedance of $A \angle \alpha$ and $B \angle \beta$ in parallel.

PROOF

The impedance of $A \angle \alpha$ and $B \angle \beta$ in parallel

is equal to $$\frac{A \angle \alpha \; B \angle \beta}{A \angle \alpha + B \angle \beta}$$

$$= \frac{OA.OB}{OC} \quad \angle \alpha + B - \theta = R$$

Now $$\frac{OF}{OA} = \frac{OB}{OC}$$

Hence $OF = \dfrac{OA.OB}{OC}$ which is the magnitude of R

Now angle of $OF = \angle B + \angle \delta$
and $\angle \theta = \angle \alpha - \angle \beta$
Hence angle of $R = \angle \alpha + B - \alpha + \delta = \angle \beta + \delta$ which is the angle of OF

Hence OF represents the impedance of $A \angle \alpha$ and $B \angle \beta$ in parallel. It can be shown that the vectors can be in any quadrant.

Yours sincerely,

JOHN L. CLARKE (A'17, M'30)
Transmission Engineer, Bell Telephone Company of Canada, Montreal

Registration of Engineers

To the Editor:

At the last meeting of the AIEE Worcester Section, our honorable and much respected chairman asked for an expression of opinion on the current vogue of compelling, by law, all engineers to register, that seems to be sweeping the country. He stated that the national organization wanted to know what we thought about it. It was immediately apparent that we had no "thoughts," as we knew practically nothing about its operation. But until we know more about how it operates, we were against it.

The question was raised as to why our national organization has not kept us informed as to what was going on. ELECTRICAL ENGINEERING has the necessary contacts throughout the country through which to solicit and secure factual data concerning the operation of such laws in the states where they are in force.

We are told by outsiders that compulsory registration will raise the standards of engineering ethics. Will exposing one's engineering training to microscopic examination by a board of politicians, engineering or otherwise, elevate these lowly ethics? It is my humble opinion that the exact contrary will be true. The whole business will immediately degenerate to a political racket. I venture the guess that in the states where engineers are required to register, be they electrical, civil, architectural, or mechanical, their profession actually has suffered through the law. I can see much embarrassment to competent engineers of long standing when confronted with the examination problem. What nice fat political jobs can be built up around the law? Why not force engineers into the CIO and call it O.K?

Let's have a little open discussion of this entire mess. It may be too late to do much about it, but it does seem that if real unsavory conditions have developed, a backfire aimed at removing the law from the books can be started and fanned into a real blaze. Surely, the men who have been forced to go over the hurdles in securing registration as engineers know what it means. They also know just what "good" or "harm" is coming from it. They will be doing a brotherly act if they will tell us their story.

Yours very truly,

LOUIS S. LEAVITT (A'24, M'28)
Assistant to Vice-President and General Manager, Worcester Electric Light Company, Worcester, Mass.

Capacitor Motors With Deep-Slot Rotors

To the Editor:

From time to time the question of the advantages of deep-slot and double squirrel-cage rotors with capacitor-start induction motors has been discussed in the technical press, but some disagreement seems to exist in regard to the practicality of such application and the results to be expected. To remove this question from the field of conjecture and to show the advantages and disadvantages of deep-slot designs was the object of the investigation described in this letter.

Characteristics are obtained by calculation. Although these are calculations unverified by tests, the skin effect of deep bars is determined by a process suggested by Punga and Raydt,[1] and which has been found to be reliable in practice.

In general, the advantages to be expected in deep-slot rotor designs for capacitor motors are a reduction of starting current per unit of starting torque and the maintenance of a given starting torque with a smaller capacitor. A limited increase in starting torque can be obtained by an increase in rotor-bar resistance. Yet if this resistance is increased too greatly it will result in less favorable running characteristics; that is, increased rotor losses with increased temperature rise and high full-load slip may accompany too large a value of rotor resistance.

It would seem then that a large value of rotor resistance at start and a smaller value for ordinary running operation would be a highly desirable characteristic. Skin effect in deep bars, to increase the apparent rotor bar resistance at starting, and to reduce it under speed, would help bring about this desirable end. Just how much advantage may be expected to accrue from such construction will be made clear by the analyses described here.

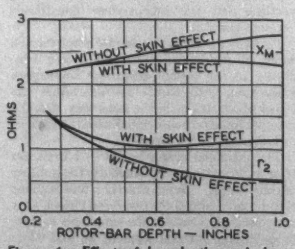

Figure 1. Effect of bar depth on leakage reactance and rotor resistance, with and without skin effect

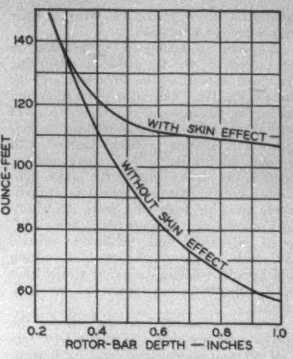

Figure 2. Effect of bar depth on starting torque, with and without skin effect (340 microfarads)

Considering the number of variables with which one may deal in attempting such an investigation, it seemed most advantageous to use the following procedure: A single-phase induction motor of medium size (¾ horsepower) and normal design was selected as the basis for an example. Because of rotor diameter limitations smaller machines were rejected as being unsuitable for an extensive change in bar depth. The rotor bars were assumed to increase progressively in depths of 0.25, 0.5, 0.75 and 1.0 inch. For each bar depth, the slot constant and hence the rotor leakage reactance varied. Also for each depth, the value of rotor resistance becomes less because of the increased bar section. Yet with each increase in depth, the skin effect at starting increases, and the resistance under this condition fails to fall off as rapidly as the physical dimensions would imply. This progressive change is

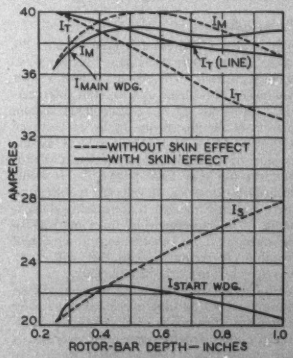

Figure 3. Effect of rotor bar depth on line currents and their components

indicated in figure 1 for both rotor resistance and total leakage reactance. It will be noted that on the smallest depth used (0.25 inch) skin effect at 60 cycles was negligible.

With the machine constants known for each of the five values of bar depth assumed, the starting torque was calculated using the same value of capacitance (340 microfarads) in each case. Starting torque was also calculated for those machine constants which would have resulted if skin effect were neglected. These results are shown in figure 2. The increased starting torque available because of the increased resistance and the decreased leakage reactance, is clearly discernible.

Starting currents, in the main and start windings, and the resulting line currents are indicated in figure 3. If the rotor bars had had no skin effect, the constants would be such as to yield starting currents indicated by the dotted lines. Comparatively little effect is noticed on the main winding current; but in the start-winding circuit, any increase in rotor resistance has a relatively larger effect on limiting the current.

Reduced line currents are obtained in capacitor motors, on starting, because the current in the main winding has a lagging component, and the current in the start winding has a leading component. To take fullest advantage of this it is necessary that the lagging component of the main winding current be relatively large with respect to its in-phase portion. Deep rotor bars are unfavorable for this reason, since skin effect decreases the reactance component of the main winding current. This shows up in unfavorably large line current I_T, larger with skin effect than without.

Another way of considering this same phenomenon is the use of the ratio of line current to the arithmetic sum of the currents in the main and the start windings. The lower this ratio is, the greater is the advantage that has been obtained from the use of a condenser in yielding smaller line

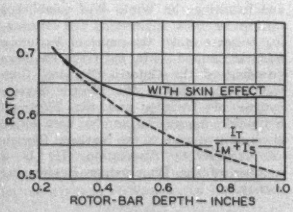

Figure 4. Ratio of line currents to arithmetic sum of main and start currents

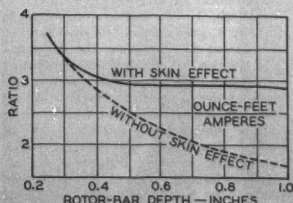

Figure 5. Ounce-feet per ampere versus bar depth, with and without skin effect

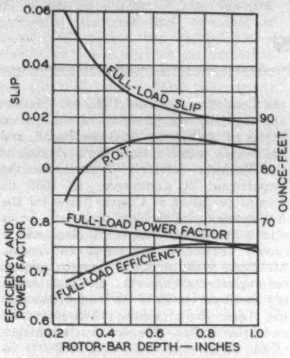

Figure 6. Full-load performance

currents. This ratio is plotted in figure 4, and it will be noted that it is consistently smaller for the decreased values of rotor resistance (that is, without skin effect). From figure 3, the locked current with skin effect becomes relatively higher as the rotor-slot depth increases, but when this is referred to an "ounce-feet per ampere versus-slot-depth" basis, the net result is still an appreciable increase of starting torque per ampere of line current. This is shown in figure 5.

Any starting characteristic described, such as favorable starting torque, or starting current, or their ratio, can be obtained by using outright the correct value of rotor resistance and rotor tooth shape, with no regard to skin effect. Yet if high rotor resistances must be used, the disadvantage will show up, not so much in starting, but in the running performance. Hence any final advantages must be judged in part by the characteristics of the motor when running. Accordingly the full-load performance (with capacitor winding disconnected) was calculated for each value of rotor-bar depth. Results are indicated in figure 6. Calculations were made by the cross-field. theory, outlined by the writers.[1] By this theory no skin effect is considered during operation at low slips. Analysis by the revolving-field theory[2] might yield slightly different results if the change in rotor leakage reactance and resistance to the forward and backward fields were taken into account. For the purposes of this paper the effect is believed to be negligible.

Examination of the entire series of curves shows that there is no "best" depth of bar or amount of skin effect. Increased bar depth decreases the starting torque per ampere and points to conservatism in depth slot design. Increase in efficiency and decrease in full-load slip make small gains after the first few steps. This would imply that extreme depth of bar was desirable only if a very minimum of slip, and the greatest possible efficiency at full load, were of great importance in the design. Improved pull-out torque is also noted by conservancy in bar depth, although a comparatively rapid initial gain is observed.

If a high starting torque per ampere with no restrictions on full load slip and pull-out torque are desired, then there is no need for

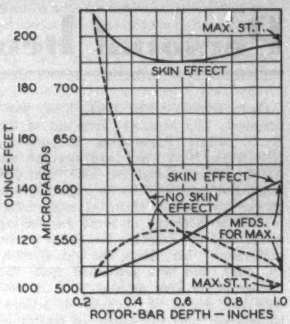

Figure 7. Maximum torque obtainable with each design, with and without skin effect

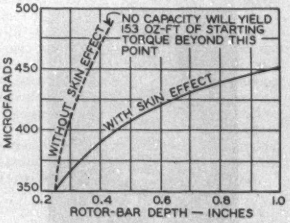

Figure 8. Capacitances required to produce 153 ounce-feet of starting torque, with and without skin effect

the deep-bar rotor. The use of deep bars and the degree to which such depth should be carried depends, in the final analysis, upon the relative importance of the various performance items on any individual application.

The motor used for investigation is rated at ¾ horsepower, 4 poles, 60 cycles, 110 volts, and the important physical dimensions are:

Diameter of rotor: 4.593 inches
Length of air gap: 0.016 inch
Stacking width: 2.75 inches
Stator slots: 36
Rotor slots: 39
Rotor-bar width: 0.109 inch
Bar depth: variable

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2. THE REVOLVING-FIELD THEORY OF THE CAPACITOR MOTOR, Wayne J. Morrill. AIEE TRANSACTIONS, volume 48, 1929, pages 614–29.

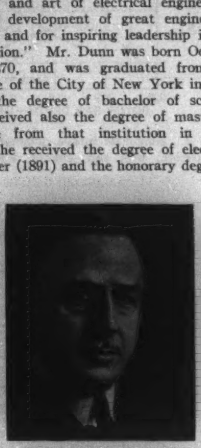
3. MODERN POLYPHASE INDUCTION MOTORS (a book), F. Punga and O. Raydt. Translated from the German by H. M. Hobart. Pitman Publishing Corporation, New York, N. Y.

Very truly yours,

A. F. PUCHSTEIN (A'20, M'27)
Chief Engineer
T. C. LLOYD (A'31)
Development Engineer
Robbins & Myers, Inc.,
Springfield, Ohio

Personal Items

GANO DUNN (A'91, M'94, F'12, past-president, Life Member) president of the J. G. White Engineering Corporation, New York, N. Y., has been awarded the AIEE Edison Medal for 1937 "for distinguished contributions in extending the science and art of electrical engineering, in the development of great engineering works, and for inspiring leadership in the profession." Mr. Dunn was born October 18, 1870, and was graduated from the College of the City of New York in 1889 with the degree of bachelor of science; he received also the degree of master of science from that institution in 1897. Later he received the degree of electrical engineer (1891) and the honorary degree of



GANO DUNN

master of science (1914) from Columbia University. He began his professional career in 1886, in the services of the Western Union Telegraph Company, where he remained five years. He then entered the employ of the Crocker-Wheeler Company at Ampere, N. J., and from 1898 until 1911 was vice-president and chief engineer of that company. In 1911 he was elected vice-president in charge of engineering and construction of J. G. White and Company, and when the J. G. White Engineering Company was organized to take over the engineering and construction work of the parent company Mr. Dunn was made president, which position he still holds. During his period of service with the Crocker-Wheeler Company, Mr. Dunn was granted many patents on generators, motors, rheostats, switches, and on systems of operation, control, and regulation. Since he has been associated with the J. G. White Engineering Company he has been responsible for the design, construction, and operation of many public utility properties, including hydroelectric systems, central lighting and power stations, electric and steam railways, and other services throughout the world. During the World War he was a member of the War Department Nitrate Commission from 1916 until 1918, and was chairman and disbursing officer of a special committee of the State, War, and Navy Departments on submarine cables in 1918. He was also a member of the engineering committee of the Council of National Defence. He was appointed by the president of the United States to the Science Advisory Board, and has been a member since the beginning of the Business Advisory Council for the Department of Commerce. In 1935 he became president of Cooper Union for the Advancement of Science and Art; he is also a trustee of Barnard College and a former trustee of Columbia University. Mr. Dunn is the author of numerous papers on engineering subjects. He has served the Institute on 12 of its committees and has been the Institute's representative on 9 other bodies. He served as a manager of the AIEE 1897–1900 and 1902–05; as vice-president, 1900–02 and 1905–07; and president, 1911–12. From 1900 until 1902 Mr. Dunn was president of the New York Electrical Society. He was president of the United Engineering Societies from 1913 to 1916; of the John Fritz Medal Board of Award in 1914. He was the first chairman of Engineering Foundation (1915–16); and vice-chairman of the National Research Council during 1917, afterward becoming chairman. He was secretary of electric lighting and distribution for the International Electrical Congress at St. Louis, in 1904, and vice-president of the International Congress at Turin in 1911. He was official delegate of the United States Government to the Second Pan-American Scientific Congress in Washington in 1915, and the third Pan-American Commercial Conference in Washington in 1927. He is honorary vice-president of the Pan American Society. Mr. Dunn is honorary secretary for the United States of the Institution of Electrical Engineers (Great Britain), and is a Fellow of the Royal Microscopical Society of London, the Institute of Radio Engineers, New York Academy of Sciences, and the American Association for the Advancement of Science. He is honorary member of the Association of Iron and Steel Engineers, and a member of the American Society of Civil Engineers, the American Society of Mechanical Engineers, Franklin Institute, Illuminating Engineering Society, Optical Society of America, National Academy of Sciences, American Philosophical Society, American Academy of Arts and Sciences, Phi Beta Kappa, and others.

H. E. IVES (F'29) electro-optical research engineer, Bell Telephone Laboratories, Incorporated, New York, N. Y., has received the Frederic Ives Medal of the Optical Society of America for distinguished work in optics. The medal was established in honor of Doctor Ives' father, a brilliant investigator in optics and a pioneer in color photography and photoengraving. Doctor Ives was born July 31, 1882, at Philadelphia, Pa., and received the degrees of bachelor of science (1905) and doctor of philosophy (1908) from the University of Pennsylvania and The Johns Hopkins University respectively. He received the honorary degree of doctor of science from Dartmouth College (1928), Yale University (1928), and the University of Pennsylvania (1929). Following his graduation in 1908 he was employed in the National Bureau of Standards for one year before becoming a physicist in the research laboratories of the National Electric Lamp Association. In 1912, Doctor Ives became a physicist for the United Gas Improvement Company, where he remained until he received a commission in the United States Army during the World War. He has been engaged in research work for the Bell Telephone Laboratories since 1919. He is the author of many scientific and technical papers and has received Longstreth Medals from the Franklin Institute for work in color photography, "artificial daylight," and studies of the Welsbach mantle. In 1927 he received the John Scott Medal, awarded annually by the City of Philadelphia, for contributions to electrical telephotography and television. Doctor Ives is a past-president of the Optical Society of America, a past vice-president of the Illuminating Engineering Society, and a member of the American Association for the Advancement of Science, American Philosophical Society, American Physical Society, Franklin Institute, Phi Beta Kappa, Sigma Xi, and many other honorary and scientific organizations in the United States and in Europe.

G. W. PATTERSON (A'37) president of Patterson Electric Limited, Toronto, Ont., Canada recently received the McGraw medal of the National Electrical Contractors Association "for outstanding contributions to the contracting branch of the electrical industry." Mr. Patterson was born November 29, 1896, at Toronto, and received his formal technical education by attending the Toronto Technical School and through the International Correspondence School. He entered the electrical contracting business in 1912. From 1916 until 1920 he served in the Canadian army, and following the World War established his own electrical engineering and contracting business under the name of Patterson Electric Limited. Mr. Patterson has been president of the Ontario Electrical Contractors Association, the Electric Service League of Toronto, and the Electrical Estimators Association, and has been active in committee work of the National Electrical Contractors Association. He is a member of the Illuminating Engineering Society.

H. L. DOHERTY (A'98, F'13, member for life) president of Cities Service Company, New York, N. Y., has been awarded the Anthony F. Lucas medal "for distinguished achievement in improving the technique and practice of finding and producing petroleum." The medal is awarded annually by the American Institute of Mining and Metallurgical Engineers in memory of Captain Anthony F. Lucas, Texas oil pioneer. Born May 15, 1870, in Boone County, Ind., Colonel Doherty never received a formal technical education but received the honorary degrees of doctor of engineering from Lehigh University and doctor of laws from Temple University. He started his career as an office boy in the

Columbus Gas Company at the age of 12, advancing through various positions until eventually he became assistant general manager of that company. In 1896 Colonel Doherty became general manager and engineer of the Madison (Wis.) Gas and Electric Company, and subsequently held similar positions with other public utility organizations until 1905, when he founded and became manager of Henry L. Doherty and Company, an organization of bankers and operators of public utility corporations. He organized the Cities Service Company in 1910, and has been the only president of that organization. He received the first Beill Gold Medal of the American Gas Light Association in 1898, and in 1930 was awarded the Walton Clark Medal of the Franklin Institute "in consideration of his outstanding and valuable work in development of the manufactured gas industry." Colonel Doherty is a member of the Association for the Advancement of Science, American Society of Heating and Ventilating Engineers, The American Society of Mechanical Engineers, Franklin Institute, and several other societies.

W. L. Upson (A'08, M'20) formerly professor of electrical engineering at Washington University, St. Louis, Mo., recently became affiliated with the Torrington Manufacturing Company, Torrington, Conn., as engineer in charge of research for the company. Mr. Upson was born July 3, 1877, at Cleveland, Ohio, and received the degrees of bachelor of science (1899), electrical engineer (1902), and master of science (1903) at Princeton University. Later he studied in the graduate schools of the University of London (England) and Harvard University. After five years of commercial experience he was appointed to the faculty of Princeton University as an instructor in electrical engineering and physics in 1904. After two years at that institution he went to The Ohio State University as assistant professor of electrical engineering, remaining there until 1910, when he was appointed professor and head of the department of electrical engineering at the University of Vermont. In 1912 Mr. Upson was appointed assistant professor of electrical engineering at Union College; later he became associate professor and remained at that institution until 1920, when he was appointed professor on the electrical engineering faculty of Washington University. Mr. Upson is author of one electrical engineering textbook and co-author of another. He served the Institute as a member of the committee on education, 1921–24 and 1933–36, and is a past-chairman (1917–18) of the AIEE Schenectady Section. He is a member of the Society for the Promotion of Engineering Education, American Association for the Advancement of Science, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

F. L. Lawton (A'25, M'36) since 1930 an electrical engineer for the Saguenay Power Company, Ltd., Arvida, Que., Canada, recently became chief engineer of the company. Mr. Lawton was born, December 14, 1900, at London, England and received the degree of bachelor of applied science in electrical engineering at the University of Toronto in 1923. Following his graduation he completed the test course of the General Electric Company, Schenectady, N. Y., and in 1924 was transferred to the general engineering department of that company. In 1925 Mr. Lawton became assistant to the electrical engineer of the Quebec Development Company and during the following year was placed in charge of drafting for a hydroelectric survey; later he was appointed assistant to the superintendent of operation, which position he held until 1930. In that year he became electrical engineer for the Duke-Price Power Company, Ltd., which later became the Saguenay Power Company, Ltd. Mr. Lawton is a member of the Engineering Institute of Canada.

Wilfred Sykes (A'09, F'14) assistant to the president of the Inland Steel Company, Chicago, Ill., has been elected a vice-president and director of the American Institute of Mining and Metallurgical Engineers. Mr. Sykes was born December 9, 1883, at Palmerton, North New Zealand, and received the degree of bachelor of science at the University of Melbourne in 1903. Following his graduation he became an electrical engineer for Knox Schlapp and Company, Melbourne, where he remained until he was employed by Allgemeine Elektricitats Gesellschaft, Berlin, Germany, in 1907. In 1909 he came to the United States and was employed by the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., remaining with that company for 11 years. Following a brief affiliation with the Steel and Tube Company of America, Mr. Sykes joined the engineering staff of the Inland Steel Company in 1923. Mr. Sykes is the author of several papers on the application of electricity in steel mills. He is a member of The American Society of Mechanical Engineers.

L. L. Carter (A'29, M'35) assistant chief engineer, Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y., has received honorable mention in the selection by Eta Kappa Nu, honorary electrical engineering society, of America's outstanding young electrical engineer for 1937 (see page 38). Mr. Carter was born June 5, 1903, at Muncie, Ind., and received the degrees of bachelor of science in electrical engineering (1927) and master of science in electrical engineering (1929) at Purdue University, following which he spent three years in the Purdue University Engineering Experiment Station in improving weather-resistant coverings for overhead line wires. Since 1932 Mr. Carter has been associated with the Anaconda Wire and Cable Company, where he has been engaged in detailed operation of the engineering and product development division, including manufacturing, research and developments, customer service, and sales promotion. He is a member of the American Standard Association, American Transit Association, Association of American Railroads, and the American Society for Testing Materials.

C. A. Faust (A'35) in charge of power utility division advertising, Ohio Brass Company, Mansfield, Ohio, has received honorable mention in the selection by Eta Kappa Nu, honorary electrical engineering society, of America's outstanding young electrical engineer for 1937 (see page 38). Mr. Faust is a native (1905) of Bellevue, Iowa, and received the degree of bachelor of science in electrical engineering at Iowa State College in 1927. Following his graduation he became associated with the McGraw-Hill Publishing Company, New York, N. Y., as a student apprentice on the staff of *Electric Railway Journal* (now *Transit Journal*), eventually becoming associate editor of that publication in 1933. In 1936 Mr. Faust transferred his affiliation to the advertising department of the Ohio Brass Company, where he is now in charge of advertising for the power utility department. Mr. Faust has been particu-

F. L. LAWTON

Chester Warner Slack

H. E. IVES

H. L. DOHERTY

G. W. PATTERSON

larly active in Eta Kappa Nu Association, having recently completed two terms as national president.

A. M. Musgrove, Jr. (A'30, M'37) formerly assistant electric distribution engineer for the Public Service Electric and Gas Company, Englewood, N. J., recently was transferred to the Bergen, N. J., division as district distribution engineer. A native (1907) of Gleneld, Md., Mr. Musgrove received the degree of bachelor of engineering at The Johns Hopkins University in 1928 and the degree of master of arts at Columbia University in 1930. Immediately following his graduation in 1928 he entered the employ of the Public Service Electric and Gas Company as a cadet engineer, and after holding several intermediate positions became assistant engineer in 1935.

P. M. Ross (A'34) has been appointed superintendent of the high-voltage laboratory of the Ohio Brass Company. Mr. Ross has been associated with the engineering department of the Barberton (Ohio) division of the company since 1934. Prior to his association with Ohio Brass Company he was with the commercial engineering department of the Frigidaire Corporation. Mr. Ross is an electrical engineering graduate of Purdue University, and is a member of Eta Kappa Nu.

G. W. Swenson (A'19, F'36) professor and head of the department of electrical engineering, Michigan College of Mining and Technology, Houghton, recently was elected president of the North-Midwest section of the Society for the Promotion of Engineering Education for the year 1938. Professor Swenson acted as vice-president of the section during 1937.

P. S. Millar (A'03, M'13) president of the Electrical Testing Laboratories, New York, N. Y., has been elected to serve as president during 1938 of the newly formed American Council of Commercial Laboratories. Mr. Millar is a member of the Institute's committee on the production and application of light.

Robert Triplett (A'32) formerly a receiving engineer at Point Reyes receiving station, RCA Communications, Inc., Inverness, Calif., recently became an assistant radio engineer for the United States Department of Commerce, Bureau of Air Commerce, Salt Lake City, Utah.

R. G. Lockett (M'37) formerly supervising engineer for Cutler-Hammer, Inc., Milwaukee, Wis., has become application engineer in the sales department of the I-T-E Circuit Breaker Company, Philadelphia, Pa.

O. G. C. Dahl (A'22, F'33) has resigned his position as professor of electric power transmission at Massachusetts Institute of Technology, to become an engineer for the consulting engineering firm of Jackson and Moreland, Boston, Mass.

E. R. Heacock (A'33) who has been a merchandise salesman for the Central Illinois Public Service Company, Mattoon, has become a group superintendent for that company.

Agustus Lehrkind (A'37) research engineer for the Burgess Battery Company, Madison, Wis., has been transferred to the Chicago (Ill.) offices of that company, where he will be engaged in the acoustic division.

H. H. Robison (A'34) who has been an electrical engineer for the Dallas Power and Light Co., Dallas, Texas, now is associated with the Texas Power and Light Company, Dallas.

C. G. Wallis (A'26) works engineer, Westinghouse Electric Elevator Company, Chicago, Illinois, has been transferred to the Jersey City (N. J.) works of that company in a similar capacity.

D. J. Corrigan (A'34) formerly a rodman for the Colorado Fuel and Iron Company, Sunrise, Wyo., now is employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

B. A. Hultberg (A'31) formerly a radio engineer for the Crosley Radio Corporation, Cincinnati, Ohio, now is employed in the engineering department of General Household Utilities Company, Chicago, Ill.

W. R. Gilsdorf (A'36) formerly a sales engineer for the National Theatre Supply Company, Cleveland, Ohio now is employed by the Spaulding Fibre Company, Cleveland.

W. A. Thomas (A'32) formerly assistant professor of electrical engineering at Antioch College, Yellow Springs, Ohio, recently became a member of the electrical engineering faculty of Iowa State College, Ames.

W. A. Uline (A'30) design engineer for the Scintilla Magneto Company, recently became associated with the engineering department of the New York Power and Light Corporation, Albany.

P. B. Garrett (A'24, M'30) engineering supervisor, Westinghouse Electric & Manufacturing Company, San Francisco, Calif., has been transferred to the Salt Lake City (Utah) offices of that company.

R. U. Muffley (M'23) commercial manager of the Puget Sound Power and Light Company, Seattle, Wash., recently was elected president of the Electric Club of Washington.

C. H. Bunch (A'16, M'32) sales manager, Acme Electric, Cleveland, Ohio, has been transferred to the newly established general offices of that company at Cuba, N. Y.

J. M. Barr, Jr. (A'37) recently became a junior engineer for the Carrier Corporation, Dallas, Texas.

M. P. Smith (A'32) engineer for the General Radio Company, New York, N. Y., has been transferred to the Los Angeles (Calif.) offices of that company.

A. U. Houle (A'27) has become a demonstrator in electrical engineering at the University of Toronto, Toronto, Ont., Canada.

J. P. May (A'30, M'36) central station department, General Electric Company, Pittsfield, Mass., has been transferred to the Atlanta (Ga.) offices of that company.

F. R. Lawson (A'34) recently joined the engineering department of the Pacific Gas and Electric Company, San Francisco, Calif.

J. L. Bronstein (A'36) now is employed by the Wisconsin Rural Electric Co-operative Association as junior electrical engineer.

E. A. Shultz (A'32) recently became affiliated with the Illinois-Iowa Power Company, Champaign, Illinois, as an electrical engineer.

Obituary

Edward Leamington Nichols (A'87, M'87, member for life) professor emeritus of physics, Cornell University, Ithaca, N. Y., died November 10, 1937. Professor Nichols was born September 14, 1854, and received the degree of bachelor of science at Cornell University in 1875, following which he went to Germany to continue his studies in physics. In 1879 he received the degree of doctor of philosophy at Göttingen, and in 1906 the University of Pennsylvania conferred upon him the honorary degree of doctor of laws. Upon completion of his studies in Germany, Doctor Nichols returned to the United States as a fellow at The Johns Hopkins University. In 1880 he joined the staff of Thomas A. Edison at Menlo Park, N. J., but after one year received an appointment as professor of physics at the Central University of Kentucky. In 1883 Doctor Nichols was appointed to the faculty of the University of Kansas, and in 1887 became professor of physics at Cornell University. Doctor Nichols was founder of *Physical Review* and was editor of that publication from 1893 until 1912. He was author or co-author of several textbooks and many papers and articles on scientific subjects. He was past-president of the American Association for the Advancement of Science and the American Physical Society, and was a member of the American Academy of Arts and Sciences, American Philosophical Society, Illuminating Engineering Society, and several other scientific societies.

Philip Bell Woodworth (A'00, member for life) counsellor at law in the firm of Rummler, Rummler, and Woodworth, Chicago, Ill., died in June 1937, according to word just received at Institute headquarters. Mr. Woodworth was born October 19, 1865, at Auburn, N. Y., and was graduated from the Michigan Agricultural College in 1886 with the degree of bachelor of science, following which he was employed by the State of Michigan as a civil engineer. He later enrolled in the engineering school of Cornell University and was graduated with the degree of mechanical engineer. After a brief association with the Brush Electrical Com-

pany, Mr. Woodworth went to Berlin, Germany, to pursue advanced studies in physics and electricity. In 1892 he returned to the United States and was placed in charge of the departments of physics and electrical engineering at the Michigan Agricultural College, where he remained until 1899 before being appointed to the electrical engineering faculty of Lewis Institute, Chicago. Later he became dean and professor of electrical engineering at that institution. During the World War he served as technical and educational advisor to the United States Army, and following the war became president of the Rose Polytechnic Institute, Terre Haute, Ind., where he remained until his retirement in 1925. He then became an engineering attorney in the firm of Rummler, Rummler, and Woodworth.

CHARLES PHILLIP RANDOLPH (M'17) vice-president of the Edison General Electric Appliance Company, Inc., Chicago, Ill., died November 30, 1937. Mr. Randolph was born at Austin, Tex., December 30, 1888, and received the degrees of bachelor of arts (1908) and master of arts (1909) at the University of Texas. In 1909 he enrolled in the graduate school of Massachusetts Institute of Technology, and in the following year was appointed a research associate in chemical engineering. During 1911–12 he was an assistant to William Stanley (A'87, M'98, F'13, Edison Medalist '12, past vice-president) in evolving electric heating apparatus for the General Electric Company, Pittsfield, Mass., following which he was placed in charge of experimental work on heating devices and later made managing engineer of the heating device department of that company. When the heating device department of the General Electric Company was consolidated with the Hughes Electric Heating Company and the Hotpoint Company to form the Edison General Electric Appliance Company, Inc., in 1928, Mr. Randolph went to Chicago to become chief engineer of the new company. He became vice-president in charge of engineering in 1937.

HARRY ARNOLD BAKER (M'29) professor of physics, John Tarleton Agricultural and Mechanical College, Stephenville, Texas, died October 19, 1937. Professor Baker was born January 20, 1872, at Pittsburgh, Pa., and received the degree of master of science at Trinity University in 1907. In 1913 he received the degree of civil engineer from Reynolds College. In 1909 he was appointed professor of science at Reynolds College and at the same time entered the graduate school of that institution. In 1913 he became professor of physics and chemistry at Randolph College and after two years went to the Wichita Falls (Texas) High School as head of the science department. From 1917 until 1920 Professor Baker held a commission in the United States Army, and following the World War became associate professor of chemistry at John Tarleton Agricultural and Mechanical College. He became professor of physics in 1923. He was a member of the Canadian Institute of Chemistry, Society of American Military Engineers, and American Institute of Mining and Metallurgical Engineers.

DAVID FRANCIS CRAWFORD (A'95, M'09, F'12, member for life) consulting engineer, Pittsburgh, Pa., died March 6, 1937, according to word just received at Institute headquarters. Mr. Crawford was born at Pittsburgh, December 4, 1864, and was educated in private schools and at the Pennsylvania Military Academy. In 1885 he became an apprentice in the machine shop of The Pennsylvania Railroad, and in 1889 was made an inspector in the test department of that company. From 1892 until 1899 Mr. Crawford held various positions with railway and manufacturing companies, and in the latter year was appointed superintendent of motive power on The Pennsylvania Railroad lines west of Pittsburgh. In 1903 he was appointed general superintendent of motive power and remained in that position until 1918, when he became vice-president of the Locomotive Stoker Company, Pittsburgh. Three years later he became president of the Westinghouse Union Battery Company, and held that position until he established his own consulting engineering offices in Pittsburgh in 1928. He was a member of The American Society of Mechanical Engineers.

LEROY CARLISLE WILLIAMS (A'15, M'26) chief specification and materials engineer, procurement division, United States Treasury Department, Los Angeles, Calif., died September 19, 1937. Mr. Williams was born January 7, 1894, at Brooklyn, N. Y., and attended the Polytechnic College of Engineering at Oakland, Calif., following which he was employed in the maintenance department of the North Western Pacific Railway Company. In 1913 he was employed in the department of operation and maintenance of the Pacific Gas and Electric Company, San Francisco, where he remained for 9 years before becoming affiliated with the department of public service of the City of Los Angeles. Mr. Williams was appointed manager of the Los Angeles district office of the Pacific Electric Manufacturing Company in 1925, and remained with that company until 1933, when he became a member of the firm of the Coast Engineering and Equipment Company, Los Angeles. He became affiliated with the United States Treasury Department in 1935.

MAX A. BERG (A'03) vice-president and secretary of the Electric Service Supplies Company, Chicago, Ill., died in July 1937. Mr. Berg was born December 3, 1869 at Chicago. After holding various positions with several electrical supply companies, he became the secretary of the firm of Porter and Berg, holding that position until 1910, when he became secretary of the Electric Service Supplies Company. Later he was given the additional duties of vice-president of the organizations.

CLIFFORD WHITMAN BATES (A'08, M'13) technical writer in the advertising department of the Leeds & Northrup Company, Philadelphia, Pa., died December 4, 1937. Mr. Bates was born March 9, 1884, at Cleveland, O., and received the degrees of bachelor of philosophy (1905) and master of science (1908) at Yale University. Following his graduation in 1905 he was appointed to the electrical engineering faculty of Yale University as an instructor and remained at that institution until 1915, when he became an engineer in the meter and installation department of the Philadelphia Electric Company. Later he became research engineer, research assistant to the chief engineer, and technical assistant to the general manager of that company. In 1930 Mr. Bates became associated with the Leeds & Northrup Company, where he remained continuously except for a brief period as assistant associate director of engineering of the Museum of the Franklin Institute.

WILLIAM FREDERICK MCLAREN (A'03, M'30) chief draftsman of the Canadian Westinghouse Company, Ltd., Hamilton, Ont., died August 19, 1937. Mr. McLaren was born at Hamilton, May 21, 1871, and was graduated from Cornell University with the degree of mechanical engineer in 1894. In 1895 he was employed by the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., and after two years with that company he went to Montreal, Que., to become a test engineer for the Royal Electric Company. In 1901 Mr. McLaren returned to the employ of the Westinghouse company at East Pittsburgh, and in 1905 was transferred to the offices of the Canadian Westinghouse Company, where he held the position of chief draftsman for almost 32 years.

WILLIAM BENJAMIN FOLLINE (A'19, M'28) electrical engineer, General Electric Company, Dallas, Texas, died November 25, 1937. Mr. Folline was born at Hiawatha, Kans., January 31, 1886, and received his formal training in electrical engineering at Pratt Institute. In 1917 he entered the test course of the General Electric Company, Schenectady, N. Y., and in the following year was transferred to the switchboard engineering department of that company. In 1921 he was transferred to the Dallas, Texas, offices of the General Electric Company, and remained there for almost 17 years.

ROBERT J. DENEEN (A'26) vice-president of the Ohio Brass Company, Chicago, Ill., died December 12, 1937. Mr. Deneen was born August 3, 1881, at Milwaukee, Wis., and was educated at Marquette Academy and Marquette University. Following three years as a sales engineer for the Johns-Manville Company, Mr. Deneen was employed by the Ohio Brass Company and was associated with that organization for 30 years, serving in the capacity of district sales manager in the Chicago area until 1928, when he was appointed vice-president in charge of Middle Western sales.

JOSEPH A. HEPP (M'30) industrial engineer for the Union Electric Light and Power Company, St. Louis, Mo., died October 21, 1937. Mr. Hepp was born November 13, 1889, at St. Louis, and received the degrees of bachelor of science in chemical engineering (1912), master of science (1914), and

chemical engineer (1920) at Rose Polytechnic Institute. Following his graduation in 1912 he became a chemist with the United Railways Company, St. Louis, and in 1914 he was employed by the Aluminum Ore Company, East St. Louis, Ill. In 1921 Mr. Hepp became affiliated with the Union Electric Light and Power Company as a research engineer; in 1925 he became assistant superintendent of electrical distribution, and later industrial engineer.

EDWARD J. PRATT (A'25) telephone engineer, Bell Telephone Laboratories, Incorporated, New York, N. Y., died December 12, 1937. Mr. Pratt was born March 11, 1887 at Glendale, S. D., and received the degree of mechanical engineer in electrical engineering at The Ohio State University in 1911. Immediately following his graduation he became associated with the Western Electric Company at Chicago, Ill., as a designing telephone engineer. Three years later Mr. Pratt was transferred to the New York offices of the Western Electric Company, and in 1925 he was transferred to the technical staff of the Bell Telephone Laboratories.

Membership

Recommended for Transfer

The board of examiners, at its meeting on December 16, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Hill, Leland H., engineer in charge, transformer division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

Oboukhoff, N. M., research professor of electrical engineering and professor of mathematical physics, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.

2 to Grade of Fellow

To Grade of Member

Bechlem, Alfred W., designing and drafting, Eastman Kodak Company, Rochester, N. Y.

Bogan, L. B., engineer, American Telephone and Telegraph Company, 195 Broadway, New York, N. Y.

Brackett, C. H., electrical engineer, Union Carbide Company, Niagara Falls, N. Y.

Butler, J. W., central station engineer, General Electric Company, Schenectady, N. Y.

Nixon, G. M., engineer, National Broadcasting Company, New York, N. Y.

Poage, F. C., electrical engineer, Ebasco Services, Inc., New York, N. Y.

Rankin, R. H., Eastman Kodak Company, Rochester, N. Y.

7 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before January 31, 1938, or March 31, 1938, if the applicant resides outside of the United States or Canada.

Ankrum, P. D., Indiana Technical College, Ft. Wayne, Ind.

Averitt, R. A., General Electric Company, Schenectady, N. Y.

Baldwin, C. H., American Steel & Wire Company, Kansas City, Mo.

Bennett, R. II, U. S. S. *Concord*, San Diego, Calif.

Bradford, R. C., Southern New England Telephone Company, New Haven, Conn.

Breth, J. E., Consolidation Coal Company, Inc., Fairmont, W. Va.

Bruce, D., Sangamo Company, Ltd., Toronto, Ont., Canada.

Chandler, R. B. (Member), Public Utilities Commission, Port Arthur, Canada.

Conrad, T. W., Graybar Electric Company, Tulsa, Okla.

Criddle, F. P., General Electric Company, Schenectady, N. Y.

Croft, C., Railway and Industrial Engineering Company, Los Angeles, Calif.

Darcey, J. F., Capital Transit Company, Washington, D. C.

Drew, G. G., Westinghouse Electric & Manufacturing Company, Newark, N. J.

Fox, G. W., Emerson Electric Manufacturing Company, St. Louis, Mo.

Fukuda, F. M., 463 Twenty-fourth Street, Oakland, Calif.

Gardberg, J., Cutler-Hammer, Inc., New Orleans, La.

Group, J. C. (Member), Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Hammerschmidt, G. L., Northern Indiana Public Service Company, Hammond, Ind.

Hagler, J. M., Southwestern Bell Telephone Company, Dallas, Texas.

Henry, T., Jr., Canadian General Electric Company, Toronto, Ont., Canada.

Howell, L. T., The Chesapeake and Potomac Telephone Company, Baltimore, Md.

Howell, W. D., Pacific Gas and Electric Company, Oakland, Calif.

Hubbard, C. R. (Member), Garlock Packing Company, Palmyra, N. Y.

Ingram, S. B. (Member), Bell Telephone Laboratories, Incorporated, New York, N. Y.

Knudsen, K. J. (Member), Hickok Electrical Instrument Company, Cleveland, Ohio.

Krachy, A. C., Brance-Krachy Company, Inc., Houston, Texas.

Kranenburg, P. J., General Electric Company, Philadelphia, Pa.

Krause, E. R., Jr., Queens Borough Gas and Electric Company, Far Rockaway, N. Y.

Lapsley, R. P., The Okonite Company, New Orleans, La.

Lehde, P. E., (Member), Electron Engineering Company, New Orleans, La.

Lee, H. R., Bureau of Reclamation, Denver, Colo.

Lefler, C. C., Kuhlman Electric Company, Bay City, Mich.

Lillquist, A. E. (Member), Cutler Hammer, Inc., Milwaukee, Wis.

Logan, E. W., Emerson Electric Manufacturing Company, St. Louis, Mo.

Maxwell, J. P., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Merritt, M. S., Tennessee Valley Authority, Wilson Dam, Ala.

Miller, G. O. (Member), Phillips Petroleum Company, Bartlesville, Okla.

Moore, H. D. MacL., Sangamo Company, Limited, Toronto, Ont., Canada.

Newman, J. M. (Member), Cutler Hammer, Inc., Milwaukee, Wis.

Oliver, J. McC., (Member), Westinghouse Electric & Manufacturing Company, Birmingham, Ala.

Peregrine, C. A., National Broadcasting Company, Denver, Colo.

Phillips, L. A. (Member), Pennsylvania Power & Light Company, Hazleton, Pa.

Poland, H. O., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Quinn, R. F., General Electric Company, Pittsfield, Mass.

Ray, W. B., United States Engineer Office, Zoarville, Ohio.

Rhoton, W. O., Delco Remy Corporation, Anderson, Ind.

Roempke, H. F., Indianapolis Power and Light Company, Indianapolis, Ind.

Ross, F. O., General Electric Supply Corporation, Tulsa, Okla.

Snyder, R. H., U. S. Electrical Motors, Inc., Brooklyn, N. Y.

Stevenson, R. E. (Member), Polytechnic College of Engineering, Oakland, Calif.

Stormont, G. I., 601 Water Board Building, Detroit, Michigan.

Taylor, T. A. I. C., Saguenay Power Company, Ltd., Isle Maligne, Que., Canada.

Templeton, E. H., Imperial Irrigation District, Imperial, Calif.

Toepperwein, E. W., Southwestern Bell Telephone Company, Dallas, Texas.

Wetherell, T. C., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Zemaitis, V. J., RCA Communications, Inc., New York, N. Y.

56 Domestic

Foreign

Alag, S. S. (Member), Mahendra and Sons, Calcutta, India.

Attard, J. (Member), 69 Strada Zecca, Valletta, Malta.

Bhattacharyya, A. B., Tinnevelly Tuticorin Electric Supply Company, Ltd., Tinnevelly, South India.

Kirkwood, I. W. A. (Member), Messrs. A. Reyrolle and Company, Hebburn-on-Tyne, England.

Lambert, G. K., 5 Church Street, Wolverton, Bletchley, Bucks, England.

Sofiano, G. C., The Electric Construction Company, Ltd., Birmingham 8, England.

Stigant, W., Bruce Peebles and Company, Ltd., East Pilton, Edinburgh, Scotland.

Tamai, A., (Member), Piazza Crispi, 3, Milano 103, Italy.

8 Foreign

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

MECHANICS. By W. F. Osgood. New York, The Macmillan Company, 1937. 495 pages, diagrs., tables, 9 by 6 inches, cloth, $5.00. Constitutes a co-ordination of mathematical theory with physical principles. The first 9 chapters present elementary mechanics from the physical point of view; the last 6 demonstrate the use of such mathematical tools as Lagrange's and Hamilton's equations in solving physical problems.

DELTA, ESTUARY and LOWER PORTION of the CHANNEL of the COLORADO RIVER 1933 to 1935. By G. Sykes. Washington, D. C., Carnegie Institution of Washington, 1937. 70 pages, illustrations, 10 by 7 inches, paper, $1.25. A study of the lower Colorado River presenting data on the flow, silt deposition, and movement of the river during the periods of time immediately preceding and following the closure of the Boulder dam.

UTILISATION of ELECTRIC ENERGY. By B. O. Taylor. New York, D. Van Nostrand Company, 1937. 342 pages, illustrations, 9 by 6 inches, cloth, $6.00. Aims to cover the whole range of the more usual applications in a single volume and in a manner suitable for a student or an engineer who does not specialize in any branch.

TRANSIENT ELECTRIC CURRENTS. (Electrical Engineering Texts). By. H. H. Skilling. New York and London, McGraw-Hill Book Company, 1937. 349 pages, illustrations, 9 by 6 inches, cloth, $4.50. A presentation of the basic principles of transient phenomena, in which abstract mathematics has been restricted to a minimum. The first 4 chapters cover inductance, capacitors, circuit equations, and the complete single circuit. The addition of chapters 5 and 6 completes a course on the treatment of networks of lumped parameters. Separate chapters take up coupled resonant circuits, circuits with variable parameters, traveling waves, operational methods of analysis, and oscillographs.

TELEVISION ENGINEERING. By J. C. Wilson. London, Sir Isaac Pitman and Sons; New York, Pitman Publishing Corporation, 1937. 492 pages, illustrations, 9 by 6 inches, cloth, $10.00. Presents the essentials of television from an engineering point of view. Various chapters include scanning methods, photosensitivity, light modulation, synchronizing, and certain special methods and equipment.

TELEVISION CYCLOPAEDIA. By A. T. Witts. New York, D. Van Nostrand Company, 1937. 151 pages, diagrs., charts, tables, 9 by 6 inches, leather, $2.25. The work "cyclopaedia" has been applied to this rather small book because it attempts to provide concise knowledge, as distinct from mere definitions. The resulting effect is as if the material in a television textbook were distributed under its alphabetical index headings, making the information more directly available.

SYNTHETIC RUBBER. By W. J. S. Naunton. London and New York, Macmillan Company, 1937. 162 pages, illustrations, 9 by 6 inches, cloth, $2.50. Presents a brief history of the attempts to produce rubber synthetically, and describes the characteristics of the more successful synthetic rubbers, including the technology and applications.

MANUAL on RESEARCH and REPORTS by the Committee on Research of the Amos Tuck School of Administration and Finance, Dartmouth College. New York and London, McGraw-Hill Book Company, 1937. 140 pages, 8 by 5 inches, cloth, $1.25. Describes the preliminary procedure and mechanics of investigating a subject, and on some of the important standards to be observed in presenting the findings. Writers of theses and research reports may find the book helpful.

Transactions

Papers and Discussions Comprising Pages 1–60 of the 1938 Volume

Electrical Studies of Living Tissue — II

Correlation Between Tissue Response and Voltage Distribution

By A. G. CONRAD, ASSOCIATE AIEE; H. W. HAGGARD, Mem. Am. Physiol. Soc.; B. R. TEARE, MEMBER AIEE

ALTHOUGH opinion differs as to whether tissue response to electrical stimulation results directly from imposed electrical quantities or indirectly from accompanying chemical changes, there is general agreement that the response occurs when a definite threshold value of some changing condition within the tissue has been reached. Bishop[1] supports the belief that response results when a definite polarization is developed within the tissue; Hill[2] associates response with a threshold value of cathode potential. We present here evidence to show that response occurs when a definite internal voltage has been built up in the tissue. Our conclusions are based on data obtained from oscillograms of this internal voltage.

In 1907 LaPique[3] established the relations between the intensity and duration of currents producing minimal responses in tissue; he described the process of excitation as analogous to the charging of a leaky condenser. Since then numerous investigators[6–9] have demonstrated that tissue possesses capacitance. Hill[2] and Blair[4] have shown that an equivalent circuit with properly proportioned constants could be used to explain the intensity duration curve obtained by LaPique.[3] In a previous paper[5] we have demonstrated the effects of tissue capacitance on the shape of the voltage waves across tissue during the passage of current impulses of rectangular wave shape.

Using the voltage wave shapes as criteria of circuit constants, this work has been extended here to define the character of the equivalent circuits. We find that for rectangular waves of current 0.001 to 0.0001 second in duration and from 1 to 10 times the rheobase (the rheobase current is the minimum current that will produce a response, that is, it is the current represented by the ordinate of the horizontal asymtote to the intensity-duration curve) value in intensity that human and frog tissue behaves electrically as a simple circuit consisting of one condenser and one or more resistors. The magnitude of tissue impedance remains constant throughout the duration of the impulse.

The correlation between tissue response and the voltage distribution in the tissue has been determined and is here described on the basis of the voltage distribution in the equivalent circuits.

General Method

In determining the electrical characteristics of tissue, a current of rectangular wave shape was applied and the accompanying voltage wave across the tissue was recorded. The numerical values of the components of the impedance thus indicated were calculated. They were confirmed by the passing of the current impulse through a suitable circuit—and equivalent circuit—containing the necessary resistances and capacitances to give a duplication of the voltage wave.

To obtain current impulses of rectangular wave shape suitable for the electrical analysis of tissue a special apparatus was developed. This apparatus and its particular advantages have been described by the authors.[5]

Electrical Characteristics of Human Tissue

We have previously[5] described the characteristics of human tissue that have led us to correlate the tissue responses with the voltage distribution in equivalent circuits. These characteristics are: (1) minimal response occurs in human tissue when the potential across the tissue reaches a certain threshold value; (2) the voltage required to produce a minimal response in different human beings may be different, but for a given individual it is a constant, regardless of the duration of the impulse; (3) the current required to produce a minimal response is a function of the duration of the impulse. The time intensity relations obtained by the authors are similar to those obtained by other investigators.

Our point of departure from previous investigations of

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A. G. CONRAD and B. R. TEARE are assistant professors of electrical engineering and H. W. HAGGARD is associate professor of applied physiology at Yale University, New Haven, Conn.

1. For all numbered references see list at end of paper.

Figure 1. Minimal response voltage waves for shocks of different durations

this kind was in recording the voltage wave across the tissue at the time of stimulation. Although the currents required to produce responses are a function of duration of the impulses, the accompanying voltages are constant for each subject.

Electrical Characteristics of Frog Tissue

The methods by which the measurements were made on the frog have been described by the authors.[5] The voltage wave of frog tissue is of distinctly different shape from that obtained across human tissue, indicating a different type of equivalent circuit. The dissymmetry between the voltage produced across frog tissue and that produced across a resistor, although only slight, indicates that the frog's tissue is not purely resistive. The circuit that most nearly expresses the electrical equivalent of frog's tissue is shown in figure 3; that of human tissue in figure 7.

Figure 1 shows 3 superimposed voltage waves produced by current impulses of different duration causing minimal responses. In contrast to the result obtained in human tissue, the peak voltages at minimal response in the frog are not constant. The relations of peak voltages to currents at minimal response for different durations have been shown.[5]

The differences between the shapes of the curves showing the relation of peak voltages to duration in human and frog tissue can be explained on the basis of the difference in the nature of the equivalent circuits of tissue. It is evident from the waves shown in figure 1 that the voltage does not drop to zero at the instant that the current is stopped. Furthermore this residual voltage appears to be constant regardless of the intensity and duration of the impulse producing minimal responses. In order to determine more accurately the magnitude of this residual voltage the sensitivity of the amplifier supplying the cathode ray oscillograph was increased so that the upper part of the voltage wave was moved off the oscillograph screen and the residual voltage appeared approximately 2 centimeters high. A series of minimal-response shocks was then administered and the corresponding residual voltages photographed. Figure 2 shows 3 such voltages for shocks of different durations. This residual voltage, when referred to the equivalent circuit, figure 3, is that which appears across the parallel part at the instant the current is shut off.

Our interpretation of these findings is that minimal response of frog tissue occurs when, and only when, the voltage across the parallel portion has been built up to a definite value.

Correlation of Equivalent Circuits to Living Tissue

An explanation of the shapes of the curves for the time intensity relations at minimal response and also the corresponding curves for peak voltages of different tissues is afforded here on the basis of the voltage produced in the equivalent circuit by the passage of current.

In the case of frog's tissue let figure 3 represent the equivalent circuit; R_1 and R_2 the number of ohms in the series and parallel portions of this circuit; C the capacity in farads; i_1 the instantaneous current in C; i_2 the instantaneous current in R_2; I the current supplied to the circuit; T its duration. A current of rectangular wave shape supplied to this circuit will produce a voltage wave corresponding to that of figure 1 and shown here in a diagram as figure 4. The distance ab (figure 4) represents the voltage across R_1 produced by the current I. When the current is shut off the voltage across R_1 disappears giving a reduction in voltage of cd. For a rectangular current wave the rise in voltage (ab) is equal to the drop in voltage cd. When the current is first applied the condenser acts as a short circuit on the resistor R_2; consequently the voltage E_2 is zero and at this instant E_1 is equal to the total circuit voltage E. After the current

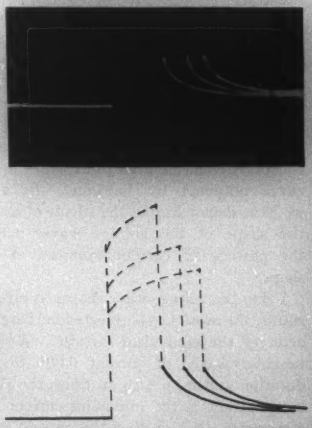


Figure 2. Threshold voltages in frog tissue produced by minimal response shocks

has flowed for some time t a voltage builds up across the condenser. The magnitude of this voltage is determined by the current I, the resistance R_2, the capacity C, and the duration of the current impulse. The voltage E_2 can be expressed by the equation

$$E_2 = IR_2(1 - e^{-\frac{t}{R_2C}}) \qquad (1)$$

The total voltage across the circuit produced by a rectangular current wave is:

$$E = E_1 + E_2 = IR_1 + IR_2(1 - e^{-\frac{t}{R_2C}}) \quad (2)$$

The first term of this equation (IR_1) is represented by the distance *ab*, figure 4; the second term $IR_2(1-e^{-\frac{t}{R_2C}})$ is represented by the vertical distance between a horizontal line drawn through *b* and the curve *bc*. Since the distance *ab* is equal to *cd*, the distance *de* is equal to E_2 at the instant the current impulse is shut off.

It has been shown experimentally that E_2 at the instant the current is shut off is constant for impulses producing minimal response. Therefore for such impulses

$$E_2 = K = IR_2(I - e^{-\frac{T}{R_2C}}) \quad (3)$$

$$I = \frac{K}{R_2(1 - e^{-\frac{T}{R_2C}})} \quad (4)$$

Equation 4 is that for the minimal-response current curve. When T is infinite the term

$$e^{-\frac{T}{R_2C}}$$

becomes zero and I is equal to K/R_2, this particular value of I being the rheobase. As the duration of the applied current is decreased T becomes shorter and the value of I must necessarily increase to fulfill the requirements of equation 4.

The voltage across frog's tissue for an impulse of a rectangular current wave can be expressed as

$$E = IR_1 + IR_2(1 - e^{-\frac{t}{R_2C}}) \quad (5)$$

but the second term, which becomes

$$IR_2(1 - e^{-\frac{T}{R_2C}})$$

at the end of any minimal-response impulse is always constant regardless of the duration T. A minimal-response impulse of short duration therefore, requires a large value of I to keep this term constant and the total peak voltage E must consequently be higher for short impulses because of the increase in IR_1.

If the peak value of $E_2 = K$ (value at the end of the impulse) for impulses of various duration are plotted against duration as in figure 5, it will be represented as a horizontal line. The first term of equation 5 (IR_1) must take the form as plotted on the same axes. The total voltage across the tissue producing the minimal response will be the sum of these 2 terms which gives a curve corresponding to the total voltage E.

Since the voltage across the parallel part of the circuit attains a definite peak value at the instant any minimal response impulse is shut off, it is evident that the peak current i_2 which flows through R_2 (figure 3) must build up to a definite peak value for each impulse causing minimal response. If this final peak value of i_2 is plotted against the duration of the impulse, it will be constant as shown in figure 6. If the impulse duration is exceedingly long so that the condenser current is zero, this peak value of current i_2 will be equal to the total current I which in this case is equal to the rheobase K/R_2.

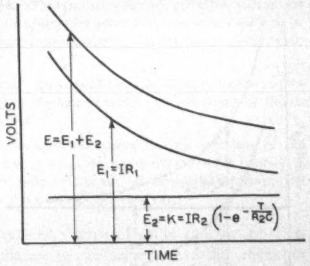


Figure 5. Peak voltages for shocks of different durations (minimal response)

From equation 4 it has been shown that the current required to produce a minimal response is

$$I = \frac{K}{R_2(1 - e^{-\frac{T}{R_2C}})}$$

(when K is the threshold voltage of the parallel circuit) and that the rheobase current, $I_{Rh} = K/R_2$. Since $I = i_1 + i_2$ and, at the instant prior to "shut off" of the current, the peak value of $i_2 = K/R_2$, then the current i_1 which flows through the condenser at this instant is

$$i_1 = I - i_2$$

$$= \frac{K}{R_2(1 - e^{-\frac{T}{R_2C}})} - \frac{K}{R_2}$$

When T is infinite the first and second terms of this equation are equal and i_1 is zero. For impulses of shorter duration the value of i_1 prior to shutting off I, will be

$$i_1 = \frac{K}{R_2(e^{\frac{T}{R_2C}} - 1)}$$

From these facts it follows that if the duration were exceedingly short the current i_1 would necessarily be infinite. The final value of i_1 for each shock of minimal response when plotted against duration is shown in

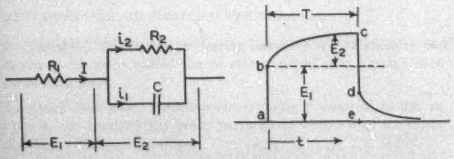


Figure 3 (left). Voltages in the equivalent circuit of frog tissue

Figure 4 (right). Voltage wave for frog tissue

figure 6. The sum of the currents i_1 and i_2 are also shown. The resultant curve expresses the time intensity relation for minimal response.

On representing the equivalent circuit of human tissue by the diagram and notations of figure 7, equation 1 (previously applied to figure 3) will represent the voltage produced across the circuit (or tissue) by a rectangular current wave. We have shown experimentally that this peak voltage is constant for any impulse producing mini-

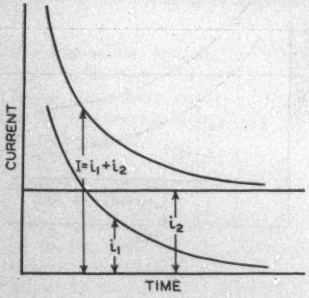


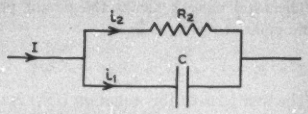
Figure 6. Peak current at instant of shut-off for minimal response shocks

mal response. The current necessary to produce minimal response is therefore expressed by equation 4. The curves shown in figure 1 can be derived from equation 2. The equation which expresses the voltage necessary to produce a minimal response in frog tissue with a rectangular current wave, is also applicable to human tissue. In this particular case R_1 is zero and

$$E = IR_2(1 - e^{-\frac{T}{R_2 C}}) = K$$

Therefore the differences in the minimal-response voltage curves of frog and human tissue can be attributed to

Figure 7. The equivalent circuit of human tissue



and explained by the differences existing in the equivalent circuits representing these tissues.

It must be remembered that an equivalent circuit of living tissue is not physiological in nature. It is used in the same manner as the equivalent circuits of other conductors of electricity, such as transformers or motors. It is used here only as a means of explaining the correlation between some of the electrical and physiological characteristics of living tissue. Other equivalent circuits could be used for this purpose. These other circuits since they are equivalent circuits naturally reveal the same correlations.

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7. The Effect of Frequency of Excitation on the Total Electric Response of Medullated Nerve, L. Bugnard and A. V. Hill. *Jl. Physiol*, volume 83, 1935, pages 394–406.

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9. Studien Über die Polarisation der Haut, S. Hozawa. *Pflüger's Arch.*, volume 219, 1928, pages 141–58.

A New High-Speed Distance-Type Carrier-Pilot Relay System

By E. L. HARDER ASSOCIATE AIEE B. E. LENEHAN ASSOCIATE AIEE S. L. GOLDSBOROUGH ASSOCIATE AIEE

Synopsis: This paper outlines the reasons for application of pilot relay equipment, particularly of the carrier-current type. A one-cycle carrier-pilot-relay scheme is described which now makes available the desirable high-speed and back-up characteristics of step-type distance protection combined with the 100 per cent simultaneous tripping feature possible with a pilot circuit. Impedance and over current supervised single-phase directional elements are utilized for controlling carrier on phase and ground faults, respectively.

Introduction

THE ADVANTAGES and necessity of rapid fault clearing have been long recognized. Improved engineering means have been gradually made available for accomplishing this object so that starting with circuit breaker operating times of a half second and relay times ranging up to several seconds 10 years ago, developments have made available up to the present day standard 8-cycle breakers and relays operating in one cycle, on a 60-cycle basis. In some instances breaker times as low as 3 cycles have been obtained.

The chart in figure 1 illustrates the gain in clearing time of transmission line faults available with increased speeds of relays and circuit breakers. Clearing times from 30 to 120 cycles are common with the 24-cycle breakers and induction-type relays using time as a basis for selectivity. A major improvement is generally available in systems of any complexity by going to high-speed relays and again by improving the breaker speed to 8 cycles. The further gain available by the addition of carrier pilot is of particular importance when the maximum clearing time for a fault anywhere in line section is the determining factor in major features of system design.

A number of such situations listed herewith are indicative of factors now leading to the application of carrier pilot protection on numerous systems.

1. *Stability.* Simultaneous clearing improves system stability and increases the loads which may be safely carried over parallel interconnecting lines.

2. *Quick Reclosing.* Simultaneous tripping is essential to fast reclosing, the combination being particularly effective in increasing stability with single tie lines.

3. *Shock to System.* System shock, evidenced by voltage dips and dropping of synchronous load is lessened by fast clearing.

4. *System Design Flexibility.* Desirable system arrangements are made possible by carrier relaying which could not be relayed with sufficient speeds to permit their use otherwise.

5. *Growth of Faults.* The more serious 3-phase and double ground faults generally originate as line-to-line or single ground and with sufficient speed of clearing the spreading to other phases is greatly reduced.

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6. *Ground Relaying Improved.* On systems where high-speed ground relaying is not feasible otherwise, carrier pilot provides an ideal solution.

7. *Out-of-Synchronism.* The carrier channel provides means for preventing operation of protective relays due to power swings or out-of-synchronism conditions while still clearing faults during such conditions.

8. *Simultaneous Faults.* The added basis for discrimination makes possible superior relay performance under the condition of simultaneously occurring faults.

9. *Joint Use.* From an economic point of view joint use of the carrier channel for point to point communication, or for control or remote metering may indicate the use of carrier pilot where thr relaying requirements alone would not justify it.

Step-type distance-relay protection is the use of 2 or preferably 3 impedance or distance measuring elements set for successively greater distances and successively longer times. The action of this principle relay protection is readily shown for a simple series connection of line sections with sources only at the ends. While practical systems are seldom so simple, the flexibility of setting provided by this arrangement in obtaining both high-speed and back-up protection has proved its adaptability to a large proportion of the systems in this country and Canada. Approximately 2,000 relays operating on this principle are in use. The importance of this point must be stressed since the provision of adequate and selective back-up protection is frequently a more difficult relay application problem than the high-speed protection.

Figure 2 illustrates the "step" characteristic tripping time versus fault location graph of a 3-zone impedance relay on a single series system. The breaker time must be added to the time here indicated to get the clearing time as shown in figure 1. The tripping characteristic of figure 2 is obtained by the use of relay elements responsive separately to 3 quantities, namely:

1. Distance of fault from the breaker.
2. Direction of fault from the breaker.
3. Time from the beginning of fault.

Three of the distance elements are required, one directional element and one timing element having 2 separately adjustable time contacts to obtain the characteristic of figure 2. The contacts on these elements are arranged in the trip circuit as shown in figure 3. Considering breaker number 1, faults to the left do not close the directional contact D. In the first zone, the directional contact D is closed together with all 3 distance elements $Z1$, $Z2$, and $Z3$. The breaker is tripped through D and $Z1$ without awaiting the closure of the timer contacts, $T2$ or $T3$. Thus, for the first zone the tripping time is simply the operating time of the high-speed directional and distance elements, normally under one cycle. The second

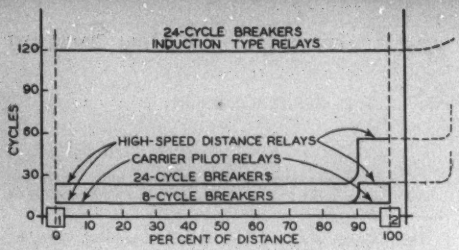

Figure 1. Reduction of clearing times by modernization

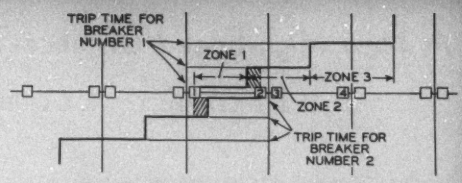

Figure 2. Chart of step-type distance relays

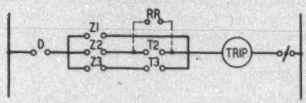

Figure 3. Elementary diagram of distance-relay carrier-current scheme

and third elements would also trip after a time delay, for faults in this region, but this is of no consequence since the first element has tripped the breaker.

The second zone is beyond the distance setting of the first zone element and $Z1$ therefore remains open for faults in this region, the tripping taking place through contacts D, $Z2$, and $T2$. The prime function of the second zone is to trip breaker number 1 for faults between zone 1 and breaker number 2. This distance is quite short, about 10 per cent of the section length, but cannot be entirely eliminated due to the practical accuracies of distance relays, current and potential transformers and application data. However, the second zone element also has a very important function in opening the breaker number 1 with suitable time delay in case of faults occurring to the right of breaker 2 on bus or lines, which are not properly cleared due to the failure or absence of apparatus to perform this function. Such failure may be in breakers, trip coils, or relays, or there may be small unprotected sections on which the expected frequency of fault occurrence does not warrant relay protection.

The third zone extends through the end of the next adjacent section so that breaker number 1 backs up breaker 3 for faults anywhere in the section 3–4. The second and third zones provide selectivity between the back-up protection of adjacent sections without the necessity of greater time settings in successive sections since the third zone for one section selects with the second zone for the next section.

The addition of carrier pilot to the scheme extends the zone of high-speed tripping up to breaker number 2, as shown dotted in figure 2 and eliminates the tripping time indicated by the shaded area. This is accomplished by a contact on the carrier receiving or blocking relay labeled RR in figure 3. This relay is controlled by the fault detectors and carrier current so that its contacts only close if the fault is within the protected section. The trip circuit is completed through D, $D2$, and RR, and also slightly faster through D and $Z1$ except for faults in the remote end zone.

The addition of carrier current pilot with separate relays for its control would involve a bulky and expensive addition to the relay equipment. It is a major purpose of this paper to show that the requirements for carrier control overlap the requirements of the distance relay elements and have made possible the combination of carrier pilot action with the step-type distance protection with very little added relay equipment.

Most of the variations in manner of utilizing the carrier pilot channel, which were considered in the earlier stages of development have been discarded in favor of the scheme which may be termed rather generally, "Intermittent With Normally Blocked Trip Circuit." The carrier is used in a straight telegraph manner, that is, unmodulated, and the principal implications of the name are:

1. That the carrier is transmitted, at least for the relaying function only at times of fault or test.

2. That advantage is taken of the inherently faster operating possibility of fault detector relays, which need not integrate effect over time, as compared with directional elements which must integrate forces over a definite time to obtain a correct operating indication. Because of this inherent difference carrier may be started and the normally blocked trip circuit may always be transferred by the fault detectors to control by carrier while the directional elements are making up their minds which way the power flows.

After the carrier is started by the fault detectors, the control of carrier and hence tripping is on a directional basis. If both directional indications point in, carrier transmission is stopped at both ends, the receiver relay closes its contacts RR and tripping is permitted.

With this general picture in mind, the requirements of the carrier controlling elements may be stated.

1. Fault detectors for starting carrier should be separate from those for tripping under carrier control, and should be set for a lower operating value, for both phase and ground faults. This is to insure that the carrier starting element at one end of the line always functions when the tripping element at the other end of the line operates. The third zone and second zone distance elements have the necessary relationship for carrier starting and tripping fault detectors, and substantially equivalent action must be provided for ground faults.

2. A directional element is required which will close a contact as rapidly as possible when and only when the fault power through the breaker is flowing into the line. Closure of this contact is necessary only if the fault lies somewhere within the protected sections. The second zone trip circuits of a high-speed distance relay possess this characteristic since at least one of them (for the faulty phase) will close through D and $Z2$ whenever the fault is within the pro-

tected section and none will close for faults back of the breaker. Also, none will close due to load conditions on the unfaulted phases since the distance elements will not be operated by loads.

Thus, the third zone element $Z3$ may be used for carrier starting and the second zone trip circuit D and $Z2$ may be used as the directional combination for controlling carrier after it is started by the fault detectors. Since these elements are available in the high-speed distance relay, they are used together with the corresponding ground elements as illustrated in the wiring diagram figure 4 and schematic diagram figure 5, showing the arrangement of a highly successful operating scheme built on the principles just outlined.

The upper part of schematic diagram figure 5 comprises the tripping circuits and the lower part of the carrier control circuits. The conventional distance type trip paths are: First zone D and $Z1$; second zone D, $Z2$, and $T2$; third zone D, $Z3$, and $T3$. The carrier-controlled tripping path is composed of D, $Z2$, and RRP contacts. For ground protection a carrier controlled trip circuit can be set up through the contacts D_0 and I_{02} of the ground relay and the carrier controlled contact RRG. The contacts RRP and RRG are on the blocking relay controlled by the carrier signal.

The contacts $Z3$ (A, B, and C) in the lower part of figure 5 serve to start the transmission of the carrier signal for phase faults and the contact I_{03} performs the same function for ground faults. These carrier start contacts $Z3$ are on the same fault detector elements as the tripping contacts $Z3$ in the upper part of the diagram. The ground carrier start contact I_{03} is operated by an overcurrent element separate from that which operates the tripping contact.

Normally, with phase and ground carrier start contacts open the grid of the master oscillator tube is connected through the resistors R_1, R_2, and R_3, the auxiliary switch coils CS, normally shorted by a $Z3$ back contact, and the resistors R_{CS} to the negative side of the battery. Under this condition the tube cannot oscillate. However, upon closure of any of the $Z3$ contacts or the ground start contact the grid is connected to the positive bus and the tube is thereby caused to oscillate.

The stopping of the carrier signal is controlled by the tripping contacts D and $Z2$ for phase faults and D_0 and I_{02} for ground faults. Closure of contacts D and $Z2$ energizes the auxiliary switch CSP which closes its contacts CSP one of which connects the point P to the negative bus. For phase faults carrier is started by $Z3$ contact which makes the grid positive and is stopped by CSP contact which connects the point P and with it the grid back to negative. However, if the ground start contact I_{03} also closes, for example, a phase to phase to ground fault, the point G and the grid are made positive and it is then impossible for the CSP contact to control the grid. In this case the carrier is stopped by the closure of the ground contacts D_0 and I_{02} energizing the CSG auxiliary switch to close the CSG contact which directly connects the grid to

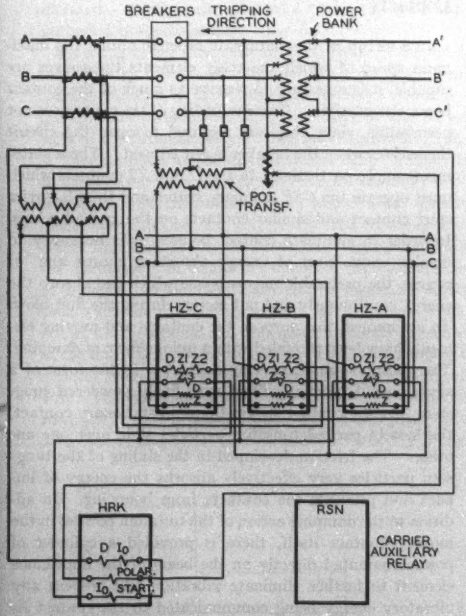

Figure 4. A-c schematic connections for distance-relay carrier scheme

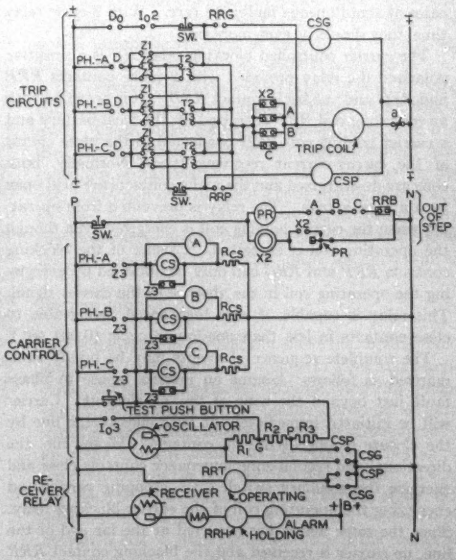

Figure 5. Schematic d-c connections of distance-relay carrier scheme

negative. Thus, it is seen that during faults involving ground, the action of the ground relays in starting and stopping carrier is given preference over the phase relays.

The purpose of this arrangement whereby the ground relays are given superiority in both the starting and stopping of the carrier signal is to prevent possible incorrect indications of the phase relays due to load currents and the flow of positive- and negative-sequence currents during external ground faults on systems with a multiplicity of grounding banks. On the other hand, in some cases it may be desirable to give the phase relays preference over the ground relays or to have no preference at all. Any one of these conditions can be obtained by a simple change in connections. If the grounding sources are of high impedance, the phase relay during an external fault may be operated in one direction by load current and the ground relays in the opposite direction at each end due to ground current. Without ground preference the line would trip out since each end has an internal fault indication. The use of single-phase directional elements with impedance supervision is very effective in reducing the possibility of load indication overriding faults on poorly grounded systems as only one-third of the load is opposed to the fault current on the active directional element. The ground preference scheme is provided in the standard system because most faults are grounds and it expedites ground clearing. The objection to ground preference action of blocking the phase relays in certain cases of 2 line-to-ground faults or simultaneous ground faults at 2 locations on a line does not apply to this system since the distance protection is still available to protect for this rare condition. Grounds are very frequent and authentic cases of simultaneous faults are rare. With 2-cycle relay time, they should be even more rare.

The carrier controlled blocking relay *RR* is a sensitive polarized d-c relay provided with 2 make contacts *RRP* and *RRG* and one back contact *RRB*. It is provided with an operating coil *RRT* energized by the local battery and a carrier holding coil *RRH* connected in the plate circuit of the carrier-current receiving tube. Normally, both coils are de-energized and the make contacts are held open by a magnetic bias. The relay is prevented from operating when the carrier holding coil is energized even though the operating coil is energized. Closure of the blocking contacts *RRP* and *RRG* can only be obtained by energizing the operating coil in the absence of the carrier signal. This relay is capable of very high speed, being able to close contacts in less than one-fourth cycle (0.004 sec.).

The complete sequence of events may be briefly summarized as follows: Assume an internal phase to phase fault just beyond the zone of the *Z*1 element. Carrier will be initiated immediately at both ends of the line by the closure of one of the *Z*3 contacts. Meanwhile, the directional and second-zone impedance contacts close and energize the auxiliary switch *CSP*, stopping carrier and energizing the operating coil of the carrier-blocking relay. Since the same action has occurred at the far end of the line, no carrier is received and the blocking contact *RRP* is closed completing the trip circuit through *D* and *Z*2. If the fault had been external to the section, then tripping could not have occurred, since the carrier holding coil *RRH* would have been energized by carrier from the far end.

If we assume a phase-to-phase-to-ground fault, the ground carrier start contact I_0 will also close, making the point *G* positive and it will be impossible for the phase relays to remove carrier through the *CSP* contacts. However, the ground tripping contacts (D_0, I_{02}) will close energizing the *CSG* auxiliary relay whose contacts can remove carrier.

Operating Time

Very satisfactory tripping times are obtained with this carrier current pilot relay scheme. The minimum times are, of course, obtained for faults within the reach of the *Z*1 elements and they are approximately 0.7 to 1.25 cycles (0.011 to 0.021 second). For faults in the end zones the tripping time is slightly longer because of the time consumed by the auxiliary element associated with the carrier and varies from 1.5 to 3.0 cycles (0.025 to 0.05 sec.), depending upon the magnitude of the short circuit current and voltage. The time consumed by the auxiliary switch *CSP* in removing carrier and included in the above time is approximately 0.3 cycle. This adds very little to the overall time in tripping, but during quick reversals of power where carrier must definitely be established at one end before it is removed from the other end of the line, this small time delay provides a positive margin of safety.

Contacts

In a circuit of this nature, in order to obtain the maximum speed of which the relay elements themselves are capable, it is necessary to remove as much of the contact bounce as possible. Current loading of the contacts is not permissible, since they are required to open the circuit themselves when the breaker is not tripped. These statements apply particularly to the *D* and *Z*2 contacts which must operate the *CSP* auxiliary switch and the *Z*3 carrier start contact and similar contacts on the ground relays. In order to eliminate contact bounce, it is necessary to employ some form of energy absorbing means and, of course, the preferable means is one which can absorb the energy continuously and not merely during the first blow. To accomplish this purpose the contacts and moving elements have been provided with a unique form of damping. The spring-mounted moving contact is in the form of a silver capsule partially filled with finely powdered tungsten. As the contact strikes the rigid stationary contact, the loosely packed tungsten particles slide over one another. The friction developed in the sliding of the tungsten particles very effectively absorbs the energy of impact and prevents the contacts from bouncing. In addition to the damping action of the tungsten powder in the moving contact itself, there is provided a cylinder of powder mounted directly on the beam of the impedance element to further eliminate vibration and prevent any vibratory energy being communicated to the contact itself. A similar arrangement is used on the directional element.

Out of Step

It is often desirable to prevent the operation of relays during out-of-step conditions as the system may pull back into step and if the system does not stabilize itself, it is then desirable to separate at locations where frequency control for synchronizing is available. The carrier signal between the 2 ends of the line provides a means of preventing tripping during out-of-step conditions without impairing the ability to trip with reasonable speed for internal faults occurring during out-of-step conditions.

The fundamental difference between a 3-phase fault and an out-of-step condition is that a fault suddenly reduces the voltages and increases the current, whereas during the approach of an out-of-step condition the voltage and current changes are comparatively gradual. For a 3-phase fault the distance elements are all operated practically simultaneously while during out of step the most sensitive distance element $Z3$ operates first, followed by $Z2$ and then $Z1$. As the system returns toward the in-phase position, the elements reset in the opposite order, that is, $Z1, Z2, Z3$.

To prevent tripping during out of step, it is only necessary to arrange for the closure of the 3 $Z3$ contacts and the receiver relay back contact to operate an additional blocking relay to open the trip circuit. This blocking relay must have a slight time delay so that it does not open the trip circuit before tripping on a 3-phase fault can occur. On the other hand, it must open the trip circuit during an out-of-step condition before the second element $Z2$ is operated. A time delay of 3 to 4 cycles (60-cycle basis) has been found satisfactory.

Referring to the schematic diagram figure 5, the out-of-step blocking contact is designated $X2$. In parallel with it are 3 contacts, A, B, C, which are the back contacts on the auxiliary switches A, B, C, operated by the $Z3$ contacts of the distance relays. The make contacts, A, B, C of these switches are in series with the back contact *RRB* of the receiver-blocking relay to energize the coil *PR* of a pendulum-type time-delay relay, whose lower contacts make and energize the coil of the $X2$ blocking relay. Every time that all 3 of the $Z3$ carrier start contacts close, the contacts A, B, C, and $X2$ open the trip circuit after 3 to 4 cycles. If the electrical center is inside the section, then when the two voltage sources are 180 degrees out of phase, the directional and impedance elements at each end of the line will be closed, removing carrier and allowing the contact *RRB* to open, de-energizing the pendulum relay *PR*. The blocking contact $X2$, however, does not immediately reset because its coil $X2$, is energized by the alternate closing of the bottom and top contacts *PR* due to the oscillation of the pendulum. After the amplitude of vibration of the pendulum has decreased to a certain value, it will not strike either of its contacts and $X2$ will reset. This time delay is adjustable and should be longer than the time during which both directional elements "point in," which depends upon the length of the "slip cycle" of the system.

It is desirable to clear internal faults occurring during an out-of-step condition, but it is not so essential to be able to clear at high speed. The ground-relay trip circuit is not blocked by the out-of-step relay $X2$ and can, of course, trip instantly. On phase-to-phase faults one or 2 of the $Z3$ contacts will reset when the system swings in phase, thus allowing one of the back contacts A, B, or C to complete the trip circuit without waiting for the reset of $X2$. On a 3-phase fault, however, none of the $Z3$ contacts will reset and, consequently, tripping will not occur until after the expiration of the $X2$ time delay. The reset of $X2$ is made possible by the opening of the receiver relay back contact *RRB*. It will be noted from the diagram that the back-up tripping through D, $Z3$, and $T3$ is shown blocked by the out-of-step contacts in which case time delay back-up protection on 3-phase faults during out of step is not possible. It is arranged, however, so that the $T3$ connection can be made on the other side of the out-of-step contacts, and in this case tripping on out of step cannot be prevented for a period longer than the time setting of $T3$.

The *power supply* for the carrier set should be unfailing. This usually means battery supply with the high-voltage direct current obtained from either of 2 inverted rotary converters with automatic-transfer equipment, supplying 115-volt 60-cycle power to the power pack of the transmitter-receiver. Recent tube developments make possible a transmitter-receiver of moderate power operating directly from 125-volt battery, without power pack.

The *communication channel* for relaying must be reliable and for this reason wave traps or tuned choke coils are used. These choke coils insert enough resistance in the line to nullify the effect of impedance changes due to switching operations on the system. All taps or dead-end connection of noticeable length should be checked as an open line. One-quarter wave length long is a short circuit at carrier frequency. If f is the carrier frequency, the wave length is $(186{,}000/f)$ miles for open wire line.

Supervision

It is desirable to periodically check the condition of the carrier set to determine its ability to send and receive a carrier signal. A means for accomplishing this manually is provided in the test push button connected in parallel with the carrier-start relay contacts. A milliammeter and an alarm element similar to the receiver blocking relay are connected in the receiver tube plate circuit. Depressing the test push button sends a carrier signal which operates the alarm relays at each end whose contacts operate a bell or other signal device. If the carrier set is not functioning, no signal is heard when the test push button is operated and this, of course, indicates trouble

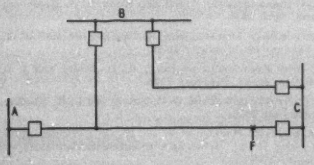

Figure 6

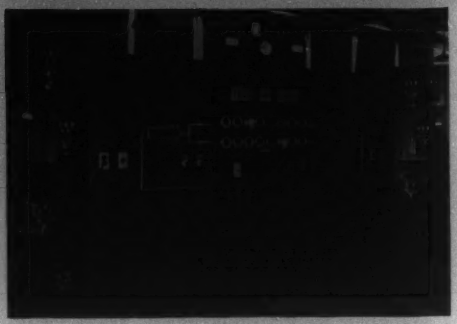

Figure 7. Two carrier-relay sets being tested on artificial transmission system

which must be investigated. The alarm receiver element has a minimum operating value in excess of the minimum value required to block the receiver relay from operating so that an indication of impending trouble can be obtained before actual failure occurs.

A periodic manual check every 8 hours is generally considered sufficient. However, if desired, an automatic periodic check can be obtained by arranging the necessary time delay relays to initiate carrier at one end of the line, transmit to the other end, and then re-transmit to the first end. If the carrier fails in either direction, an alarm is sounded.

Figure 6 is more or less typical of certain existing lines which must be protected. The application of carrier current protection alone to such a line will not operate in all cases, as the fault current flow may not be into the line at all three terminals. For example, with a fault at *F* and a high impedance source at *B*, a portion of the fault current will flow over the parallel line between *B* and *C*. The direction being out at *B* carrier will be transmitted, blocking all terminals. With distance protection added, breaker *C* will trip on the first zone setting and as soon as the breaker has cleared *B* and *A* will trip through the carrier relays This will be somewhat faster than the second zone time step of the impedance protection as there is no time added to allow for long time clearing. Tripping occurs immediately after the first breaker opens, while the timers must be set longer than the maximum relay plus arcing time.

The carrier starting element is required to start transmission on the occurrence of a fault in the range of the relay setting. For grounds either the line residual current may be used or grounding transformer neutral current. In the latter case, auxiliary switches on the breakers should be used to prevent starting when breaker is open, this is essential on three terminal lines where the line may be energized with one terminal open.

All through the development, the idea has been kept in mind to prevent tripping a good line and to clear a faulted line at the highest practical speed consistent with the above requirement. Greater tripping speed is possible, but with less security against errors. In the testing of various sets of equipment on the laboratory artificial line several hundred faults have been applied with no failures to operate correctly, which could not be traced to some defects in connection or associated apparatus.

Conclusions

1. Zone-arranged distance relays having separate impedance measuring elements for each zone contain inherently the necessary carrier controlling and tripping circuits for the intermittent-normally blocked carrier pilot relay system.

2. The zoned distance type carrier-pilot relay system affords the economic possibility of installing high-speed distance relays at one stage in the development of a project and adding the carrier later when simultaneous clearing of all faults is economically justified.

3. With the 3-zone impedance-type carrier-pilot scheme protection of the best type available prior to the carrier relay development is afforded during intervals when the carrier equipment is out of service.

4. Spare or "transfer" breakers equipped with this relay complement may be switched into use on carrier pilot or high-speed distance relayed lines using the same distance relays in either case.

5. The 3-zone distance-type carrier-pilot scheme having a first zone independent of carrier provides proper clearing in most cases of multiterminal lines where fault power may flow *out* at one or more terminals during an *internal* fault on the protected line.

6. Experience in over 2,000 installations of the zoned distance arrangement both with and without carrier pilot has shown it to be more flexible in obtaining selectivity of back-up protection with the balance of the system relaying, than any other known arrangement.

7. Greatest flexibility in testing arrangements and in substitution and addition of elements to meet individual system relay requirements is afforded by individual switchboard mountings of phase and ground relays and auxiliaries. This has proved generally more satisfactory than the mounting of all elements in a single case with greatly restricted availability of interelement connections for test and interconnection with special elements.

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Some Engineering Features of Petersen Coils and Their Application

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THE TUNED-REACTANCE method of grounding a system neutral was first disclosed by Professor W. Petersen of Germany in 1917 (German patent number 304,823). It has been used extensively in Europe and other parts of the world and the number of installations in the United States recently has been increasing rapidly, which suggests that there is a place for the Petersen coil in American grounding practice. Tracing briefly the installations of Petersen coils in this country, the first one was made in a 44-kv system in 1921. Operating records on this system showed that the Petersen coil had improved service considerably. A second installation of 2 coils was made in a 140-kv system in 1931. Again expected improvements in service were substantiated. Further installations were made in 33-kv systems in 1935 and 1936. Although favorable reports on service continuity were given on all these installations, up until 1937, a period of approximately fifteen years, only a total of five coils were installed in systems in the United States. During the same period approximately 1,700 Petersen coils were installed in systems in other parts of the world.

In recent months, 12 more Petersen coils have been purchased for installation in systems in various parts of this country. When these installations are completed, it will bring the total number of Petersen coils in the United States to 17, protecting more than 3,000 miles of line of voltages ranging from 33 kv to 230 kv. Further installations are being contemplated by operating companies. A summary of the various applications of Petersen coils in this country is listed in table I.

It is the purpose of this paper to discuss how electric service may be substantially improved with Petersen coils. Furthermore, a résumé of some of the practical design and application features of Petersen coils will be given, based upon the experience obtained from the previously mentioned installations.

The Place for the Petersen Coil in Grounding Practice

Possibly one of the reasons there is renewed interest in the Petersen-coil method of grounding a system neutral is the fact that it has proved to be a simple, effective, and relatively inexpensive means for eliminating the short-circuit currents and service interruptions usually associated with ground faults on overhead systems when the neutral is arranged in any other way.

It is generally known that a system operated with its neutral isolated from ground may be subjected to transient overvoltages due to arcs to ground during ground faults. Such a disturbance may not confine itself to the original faulty circuit but may spread to remote sections of the system and involve other phases. Experience has shown that the possibility of such trouble increases as system voltage and mileage increase. Grounding the system neutral solidly or through relatively low impedance will reduce the transient overvoltages, but in arranging the neutral in this way a momentary flashover to ground on one conductor becomes a short circuit which must be cleared by de-energizing the circuit. Thus, with either the neutral grounded or isolated, an interruption to service may occur.

The Petersen coil or tuned reactance method of grounding eliminates the transient overvoltages of the isolated neutral system and the short circuits of the grounded neutral system by extinguishing automatically the arc at the point of fault. Thus, one advantage of the Petersen-coil method of grounding from the viewpoint of those interested in maintaining service is that it eliminates the outages associated with flashes to ground usually encountered when the system neutral is otherwise arranged. Ground faults usually cause the majority of outages on overhead transmission lines as may be seen by referring to the latest report[1] of the subcommittee on grounding of the protective devices committee. This report gives information obtained from 27 systems which shows that the percentage of the total faults involving ground varied from a minimum of 30 per cent of a maximum of 97 per cent, with an average of 69 per cent. Thus, it may be reasoned that the elimination of the outages associated with ground faults will result in a substantial improvement in service on many systems.

Ground faults may be caused by lightning, wind, sleet, tree branches, birds, etc. A 5-year average of the probable causes of ground faults on systems ranging from 26 kv to 220 kv has been given in a recent AIEE paper.[2] It shows that 73 per cent of the ground faults are probably due to lightning and the rest to "other causes." The Petersen coil is capable of quenching flashes to ground from all transitory causes. It prevents the flash to ground from developing into a short circuit which disrupts service.

The Petersen Coil

The fundamental theory of the Petersen coil has been thoroughly treated in various papers. Therefore, this discussion will be limited to some of the practical aspects of an application.

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1. For all numbered references, see list at end of paper.

Table I. Petersen Coils in the United States

Power Company	Date of Installation	Number of Coils	System Voltage (Kv)	Approximate Miles of Protected Overhead Line	Line-Supporting Structures	Remarks
Alabama Power Company	1921	1	44	93	Wood poles	81 miles of overhead ground wire
Georgia Power Company	1929*	1	38	129	Wood poles and steel towers	97 miles wood poles, no ground wires
Consumers Power Company	1931	2	140	275	Steel towers	All but 40 miles of line without ground wires
Central Maine Power Company	1935	1	33	560	Wood poles	No ground wires
Public Service Company of Indiana	1936	1	33	160	Wood poles	No ground wires; 4,250 feet 3-conductor cable
Public Service Company of Denver, Colorado	1937	1	95	187	Wood poles and steel towers	31 miles of wood poles; 156 steel towers; no ground wires
Public Service Company of Indiana	1937	4	33	1,300	Wood poles	No ground wires.
Metropolitan Edison Company	1937	3	66	320	Wood poles and steel towers	127 miles wood poles; 194 steel towers
Public Service Company of New Hampshire	1937	1	33	120	Wood poles	No ground wires
Consolidated Gas and Electric Light and Power Company	1937	1	33	30	Wood poles	No ground wires; 3,000 feet 3-conductor cable
Southern California Edison Company	1938	2	230	260	Steel towers	2 overhead ground wires
	Total	17				

* Coil formerly on Alabama Power Company.

The quenching of an arc by the mechanical separation of contacts as in an oil circuit breaker is so universally used and understood that often a mental hurdle has to be cleared before it can be conceived that an arc can be extinguished otherwise. The Petersen coil puts out an arc without the aid of any moving parts by limiting the current in a flash to ground to a relatively few amperes and keeping the rate of rise of the recovery voltage low.

Theoretically, the leading charging current of the system is neutralized by the lagging inductive current from the coil which results in zero current in the fault. In practice, this is approximated as closely as conditions will permit.

The current in the fault consists of several components as shown in figure 1. Leading current is derived from the inherent capacitance in the lines, insulators, transformers, and other connected apparatus. Capacitance is usually considered to be a constant. Actually it has been observed to vary with weather conditions and corona. Measurements have been taken on a Petersen-coil-equipped system which show that the capacitive reactive current increased approximately 5 per cent during stormy weather. Corona also increases the charging current.

The lagging component of current comes from the Petersen coil. The coil reactance is high which permits the system neutral to be almost fully displaced during a ground fault.

With complete neutralization of the charging current, there is still a small amount of current remaining in the fault. This is an in-phase component of current and is derived from the resistance in the series and shunt paths in both the capacitive circuits and the Petersen coil. Corona loss will also increase the in-phase component of current. There is also harmonic current in the fault. The Petersen-coil impedance is too high for harmonic currents to return in any appreciable magnitude through the system neutral so they must return to the system through the system capacitance. On those systems which have installed Petersen coils to date, the third harmonic has been almost completely absent. The fifth harmonic has been present in some instances but there has been no occasion for compensating for anything other than the fundamental component of charging current. Harmonic currents of any appreciable magnitude higher than the fifth have not been observed.

The oscillogram on figure 2 shows the current in a Petersen coil and in the arc which was taken during a staged test on a 33-kv system. The harmonics are plainly visible in the arc current. System phase-to-phase voltages are also shown. It is to be noted that the fault produced no change in these voltages with the result that the connected load on the system was unaware of the disturbance.

Whatever fundamental frequency in-phase component of current is present in a ground fault is in phase with the line-to-neutral voltage of the faulty phase and is easily interrupted. In considering arc extinction, the magnitude of the residual current alone is not the only consideration. The magnitude of the recovery voltage at the time the current passes through zero is far more important. Should the current in a ground fault lead or lag behind the neutral voltage of the grounded phase by approximately 90 degrees, and an interruption be attempted at a current zero, there is full line-to-neutral voltage available to re-establish the arc. This condition obtains when the neutral is isolated or solidly grounded. If the fault current and voltage are in phase, the voltage phases through zero at approximately the same time the current does, and accordingly, the recovery voltage is low and the arc easily ex-

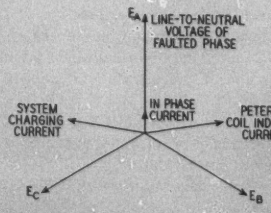


Figure 1. Vector diagram showing relation of the components of current in a ground fault on a system with Petersen coil

tinguished. This latter case occurs when a Petersen coil is in tune with a system. The significance of the part the recovery voltage takes in arc extinction may be demonstrated by staged tests on a Petersen-coil-equipped system by applying arcing faults with the coil detuned so that there is a predominance of either leading or lagging current in the fault as has been done on several occasions.

Successful arc extinction has occurred on a system[9] equipped with Petersen coils with the magnitude of the in-phase component of current as high as 50 amperes, and there is reason to believe that this current is not the outside limit that can be successfully handled.

Factors Influencing Characteristics of a Petersen Coil

The insulation on a Petersen coil is dictated by the voltage to which it is subjected. As it is a grounding impedor of special characteristics, designed for location between the system neutral and ground, it is subjected to dynamic neutral-to-ground voltages during ground faults.

In Europe, the Petersen coil has been insulated for the system line-to-line voltage and no protective equipment has been provided. In this country, Petersen coils have been insulated for system leg voltage and in addition, protective equipment has been furnished which is an integral part of the coil, consisting of either a station-type Thyrite lightning arrester or Thyrite resistor. An internal view of a Petersen coil showing the Thyrite resistor is given on figure 3.

Petersen coils installed in this country have all been constructed with iron cores except the one for the Alabama Power Company. This latter coil was a coreless reactor and service experience with it showed that it produced surges on switching operations, making it necessary to short circuit it during switching. It was found that unequal pole opening on one of the system oil circuit breakers put the coil and system into series resonance. Series resonance may tend to occur when there is an unbalance in the system voltage to ground, but no ground fault is present. Trouble of this nature has been entirely absent on all subsequent installations and was eliminated by constructing the Petersen coils with iron cores. These cores are specially designed to saturate on overvoltages. Saturation changes the coil reactance and destroys resonance. The protective equipment included is for the purpose of rendering harmless the transient overvoltages which might reach the coil through the transformer in the neutral of which it is connected.

The current rating of a Petersen coil is established by the system charging current. The coil is designed to pass an inductive reactive current which is equal in magnitude to the system charging current in the 2 healthy conductors when the third conductor is grounded and the system neutral is at leg voltage above ground.

The charging current in a line-to-ground fault on a system is not subject to precise calculation as there are many factors to be considered which cannot be readily analyzed. The location of the equivalent ground plane; the effect of the supporting poles or towers on the transmission lines; substation structures, and trees along the right-of-way; the variation in sag, angles and bends in the lines, etc., and capacitance in connected apparatus, all influence the capacitance to ground and make it extremely difficult to predetermine exactly what the charging current will be.

Experience has shown that the charging currents calculated by the aid of Maxwell's coefficients should be used with caution, especially on the medium voltage lines. Measurements on several 33-kv systems have given charging currents as high as 50 per cent in excess of calculations for the line configurations in use. For medium voltage circuits with overhead lines, the measured charging current has varied between 4.8 and 6.7 amperes per 100 miles of line per 10 kv of voltage. For high-voltage circuits, Maxwell's coefficients have given the correct current within 10 per cent if corrections for corona are included.

Ammeter measurements of system charging current in solid conductor-to-ground faults will usually give currents in excess of requirements for the Petersen coil. Such measurement includes harmonic currents. The Petersen coil functions on the fundamental component of current only and accordingly due allowance must be made for the harmonic currents.

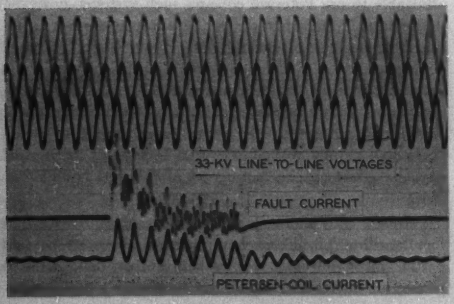


Figure 2 (left). Oscillogram showing the extinction of arcing fault by Petersen coil

Figure 3 (right). Interior view of 33-kv Petersen coil showing Thyrite shunting resistor

The Petersen coil winding is tapped so that its inductive reactance may be matched with the capacitive reactance of the system. Additional taps are usually included so that variations in system capacitance resulting from switching or system growth may also be compensated. A current range on a coil greater than 3 or 4 to 1, however, is usually considered inadvisable because with a wider current range, a sufficient degree of saturation cannot be obtained in the iron core. If a greater range is required, 2 or more coils are recommended with the current requirements proportioned among them and provision made for switching them in and out of service as required. The taps on the coil are brought to a suitable position switch, the handle of which in the later coils is located on the side of the tank where it is convenient for adjustments as shown on figure 4. Taps are provided so that accurate tuning can be readily obtained. The number of these has varied in different coils from 10 to 25. The taps are so proportioned that the current output of a coil may be adjusted in increments varying between five and ten per cent of the current rating.

The thermal characteristics of a coil are usually established by whether or not the system has means for locating and segregating permanent ground faults. Petersen coils with 10-minute time ratings are recommended for systems that must remove all ground faults promptly. Time ratings shorter than 10 minutes are discouraged as a multiplicity of temporary faults may occur in rapid succession and overheat a shorter time rated coil. Petersen coils with continuous time ratings should be used where the ground fault is likely to remain on the system for a considerable time. Experience has also shown that when permanent faults have to be located by cut-and-try methods, time ratings of at least one hour are advisable.

Petersen coils are either furnished with conservators or gas-seals. A coil with a conservator is shown on figure 4.

General Application

Petersen coils may be applied to any transmission system or network. System voltage is no limitation on the application. Theoretically, one Petersen coil is sufficient to protect all parts of an entire system which are metallically interconnected. However, if the system is extensive, it is advisable to install several small coils rather than one large one. The combined current ratings of the coils should equal the total charging current of the system. With several coils located in selected sections of the system, the loss by switching a section out of service will not appreciably affect the protection for the remainder of the system. On systems with a limited number of miles of line, Petersen coils for compensation of charging currents under 5 amperes usually prove to be uneconomical.

Petersen coils may be applied to systems which are operated at present with the system neutral grounded or isolated. If the system neutral has been grounded, a check must be made to determine if all apparatus connected between the lines and ground, such as, for example, transformers and lightning arresters, are insulated for the system line-to-line voltage. Power transformers with graded insulation may be used with Petersen coils in their neutrals, provided the neutral insulation is suitable for line-to-neutral voltage. If the system neutral has been isolated, then usually there is little question but what the connected apparatus is suitable.

Petersen coils are designed for location between the system neutral and ground. The neutral of any convenient power transformer bank can be used for this purpose or, if none is available, grounding transformers will have to be installed. Attention should be called to the fact that during ground faults, the Petersen coil imposes an additional burden on the power transformer. This usually is not serious unless operation for extended periods is contemplated with one line conductor solidly grounded. In the latter case, a reduced power load on the transformer may be advisable; the exact amount to be specified by the transformer manufacturer. If grounding transformers are to be used, the additional burden imposed by the Petersen coil should be considered in determining its characteristics. On large networks, the use of a multiplicity of coils tends to decrease the Petersen coil burden on individual power transformer banks.

The exact location of a Petersen coil in an area to be protected is immaterial as far as the proper functioning of the coil is concerned. It is desirable, however, from an operating viewpoint, to have it in a centrally located position preferably where the transmission lines radiate to the various parts of the system so that the usual switching operations will not separate the coil from a major portion of the system.

Petersen coils will not function properly if the system on which they are installed is metallically connected to a solidly grounded-neutral system because the solid-neutral grounds in effect short circuit the Petersen coil. Likewise, an interconnection with an isolated neutral system requires retuning of the coil. Two systems, each properly compensated with Petersen coils can be interconnected without any adjustments of the coils. Tuning is not critical. On medium-voltage systems, different sections may be switched out up to possibly 25 to 30 per cent of the total mileage of the system and still obtain successful arc extinction without retuning for the new conditions.

Systems interconnected through autotransformers are in effect metallically connected together and if Petersen coils are to be used, they must be designed to compensate for the charging current of all the lines metallically connected to both sides of the autotransformers. It is inadvisable to use Petersen coils on such systems, however, if the transformation ratio of the autotransformer is appreciable because of the dynamic overvoltage that may be impressed on system apparatus during ground faults resulting from neutral displacement.

Systems with transmission lines of appreciable length of different voltage ratings on the same supporting structures may require special attention because of the mutual capacity effects between the lines of different voltage ratings.

Petersen coils should not be considered as a substitute for lightning protective equipment in substations and switch yards. It is a service rather than an apparatus protective device and should not be considered otherwise.

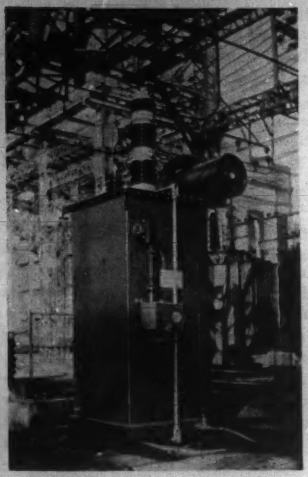


Figure 4. View of Petersen coil installed on 33-kv system

Petersen Coils and Ground Relays

An American solution of the arcing-ground problem has been to ground the system neutral solidly or through a relatively low impedance and install a selective system of ground relays. Consequently, the question is often raised as to the merits of applying Petersen coils to a system so equipped.

The addition of a Petersen coil will prevent the ground relays from functioning on all transitory ground faults, and thus eliminate many unnecessary line outages. If the fault is persistent, means may be provided for regrounding the neutral so that the ground relays can function to clear the faulty section. Thus, the Petersen coil may be considered to be a supplement to the ground relays; a device which prevents them from operating on all except permanent ground faults.

A small percentage of the ground faults on a system are a result of damage to the system insulation and must be located and segregated from the rest of the system by oil circuit breakers. The most positive way of locating such faults on a Petersen coil equipped system which has been proposed to date is to use a system of ground relays which responds to ground faults when the system neutral is directly grounded. The reactive current passed by a Petersen coil during a ground fault is insufficient to operate a selective system of ground relays but by arranging to bypass the Petersen coil and ground the neutral directly, when a permanent fault occurs, the relay system can be made to function when it is needed. This requires a suitable single-pole switch in parallel with the coil with control equipment which will close the switch after the ground fault has persisted for a definite predetermined time. Operating experience with Petersen coils to date indicates that approximately 15 seconds is ample time for a ground fault to clear if it is going to be extinguished automatically.

On a system grounded at one point, the relaying for ground faults is the simplest because the flow of fault current is all in one direction. The addition of a Petersen coil to such a system is a very simple procedure.

On a network grounded at several points, the relaying for ground faults becomes more involved because on occasions the network may be divided into sections. Neutral ground points should be located in each section if ground relaying is to be obtained under all conditions. For like reasons, Petersen coils should be located in each individual section of the system if protection is to be obtained at all times. On such a system, single-pole switches for short-circuiting the Petersen coils should be furnished for making the ground relays operative. Additional solid-neutral ground points over and above those in which the Petersen coils are located may be needed for selective relaying. Suitable switches in these neutrals functioning on zero-sequence voltage will provide these additional ground points. The far ends of radial feeders from a network may be relayed on zero-sequence voltage rather than zero-sequence current when there is an infeed of power at the far end. In this case a faulty radial feeder would clear in cascade, the near end first on residual overcurrent. This would leave the line with the neutral ungrounded for a brief interval of time, but the possibility of arcing grounds occurring is nil because the fault would be a direct ground.

In Europe, attempts have been made to relay on the uncompensated in-phase component of current in case of permanent ground faults. This requires a watt type of relay which is usually not very difficult to manufacture. However, as the magnitude of this in-phase current is small to begin with and varies with seasonal changes, the characteristics of the individual current transformers used with the relays must be matched very closely if selective relaying is to be obtained. The best information available indicates that these watt relays are used for fault indication rather than for tripping oil circuit breakers. On the occurrence of the fault, the station operators determine which feeder has relays that show an infeed of fault current at both ends. This circuit is then tripped by hand. This is also in keeping with the established practice in many parts of Europe of operating with one conductor grounded for considerable periods of time until it is convenient to remove the faulty feeder from the circuit. Operating with one conductor grounded for extended periods in this country will probably seldom be resorted to on overhead systems because of the possible hazards to safety, communication, etc.

Description of Systems on Which Petersen Coils Are Installed and Their Service Record

The Alabama Power Company Petersen coil was located on a 93-mile section of their 44-kv system. The lines were carried on wood poles, of which all but 12 miles were equipped with one overhead ground wire at the peak of the poles. All poles had down wires. During a period of slightly over 2 years this coil operated approximately 360 times, about 90 per cent of which were recorded as correct. The first year's operation indicated an 83-per-cent reduc-

tion in the number of interruptions over that obtained for the previous year.

This coil was kept in service about 4 years on this system. At the end of this time, the system outgrew the coil and it was removed from service. In March 1929, this coil was installed in the Marietta transmission substation of the Georgia Power Company's 38-kv system.

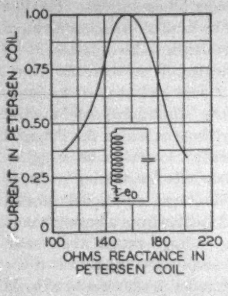


Figure 5. Tuning curve with no conductor grounded

This system has 129 miles of overhead line, 97 of which are wood poles without down wires or ground wires. On June 4, 1931, immediate initial reclosure was applied to the feeder circuit breakers. This company reports that the latter method of protection is so superior to any other method yet tried for improving service to radial feeders that little time has since been spent in analyzing the Petersen-coil performance, and data on its performance were not available at the time of writing this paper. It appears from other information sent us on this system that most of the tripouts from lightning resulted from phase faults and if this is the case, then the Petersen coil will prove to be of little use to them in improving service continuity.

The Consumers Power Company's 2 Petersen coils are installed on a 275-mile steel-tower section of their 140-kv system. All but about 87 miles of this system is single circuit and about 140 miles is without ground wires.

The operating record on this system shows that approximately 70 per cent of all the faults that occurred in 5 years' time were cleared without oil-circuit-breaker operation. In this period 242 faults were recorded with 171 extinguished by the Petersen coil.

The Central Maine Power Company's Petersen coil is installed on their 33-kv system. Five hundred and sixty miles of line of wood poles with pin insulators are protected with one coil. No overhead ground wires or down wires on the poles are used. In the first 14 months after installation, this coil operated 54 times and cleared all ground faults, which were not permanent faults, without a service interruption. On this extensive system, before the coil was installed, simultaneous faults in different parts of the system were quite numerous. Since the Petersen coil has been in service, this type of trouble has been mostly absent.

The Public Service Company of Indiana has 5 Petersen coils protecting more than 1,500 miles of 33-kv lines. These lines are supported on wood poles with pin insulators and, in general, are without ground wires or down wires. These coils are located in their Newcastle, Edwardsport, Lenore, Dresser, and Bedford Stations. The last 4 named coils, at the time of writing this paper, have not been in service long enough to have established a service record. The Newcastle coil has been in service for a longer period and the operating record has been watched with keen interest.

The 33-kv system in which the Newcastle Petersen coil is located is normally not interconnected with any of the other 33-kv lines. Approximately 80 miles of overhead line and 4,250 feet of 3-conductor cable constitute the usual operating set-up although on occasion a total of 160 miles of overhead line may be protected by the coil.

The operating record shows that 91 per cent of the faults on this system were cleared without a tripout. This operating record does not extend entirely through the severe part of the lightning season. Based on the record available, however, lightning caused approximately 25 per cent of all the faults. The ground faults which were successfully cleared resulted from wind, sleet, tree limbs, and lightning. This company reports that it is extremely well pleased with its Petersen-coil equipment.

The Public Service Company of Colorado has one coil in a 187-mile system operating at 95 kv. This line has 31 miles of wood poles and 159 miles of steel towers without ground wires. The neutral of this system was solidly grounded before the Petersen coil was installed. The operating record, month by month, on this system after the Petersen coil was installed, has been steadily improving. At first, a number of outages occurred which were apparently the result of somewhat defective insulation and incorrect relay operations. The latest monthly operating reports, however, indicate that these conditions have been remedied because approximately 73 per cent of all of the faults in these later months have been cleared by the Petersen coil. A detailed report of this installation has been given in a companion paper at this midwinter convention.[13]

The other installations of Petersen coils which have been made recently have not been in service long enough to have a report on their record. A summary of some of the system characteristics of these latter Petersen-coil installations, however, is given in table I.

The question is often raised as to the performance to be expected from a Petersen coil on a wood-pole line. The reasoning was that owing to the high insulation value of wood, most of the faults from lightning would involve more than one phase as the flashover potential between phases would be lower than from one phase to ground. The operating records on the several installations of Petersen coils on wood-pole lines previously mentioned show definitely that ground faults from lightning are obtained. One possible explanation of this is the fact that most wood-pole lines are guyed every few structures which provides a low-impedance path to ground. Also it is to be remembered that lightning is not the only cause of trouble. Studies, also previously mentioned, showed that lightning caused about three-quarters of all line interrup-

tions and on medium-voltage lines, the proportion of faults attributed to lightning is often less. Although the operating experience with Petersen coils on wood-pole lines during lightning seasons has been good, the probability is that it would have been even better if every pole on the lines in question had down wires and low footing resistance.

Determination of the Optimum Tuning of a Petersen Coil

When a Petersen coil is installed in a system, it is necessary to match the inductive reactance of the coil with the capacitive reactance of the system. Taps are provided on the coil winding so that its reactance can be adjusted to meet the system requirements.

The proper setting of a Petersen coil may be determined by calculation if the charging current of the system has been accurately determined. Usually it is desirable to check at least one adjustment by test at the time the coil is put in service. These tests may be conducted during normal conditions (no conductor grounded) or with one conductor solidly grounded.

During normal conditions of operation, there is usually some slight unbalance in the system phase-to-ground voltages. This unbalance is sufficient to cause a small amount of current to flow continuously through the coil. For tuning tests, the coil ohms are varied and the current through the coil noted for each tap position. A typical plot of the coil current as a function of the ohms reactance in the coil taken on a 33-kv system is shown on figure 5. Correct tuning is obtained on the tap that results in maximum amperes.

The shape of this curve may be explained by understanding that the inductive reactance of the coil and the capacitive reactance of the system form a series resonant

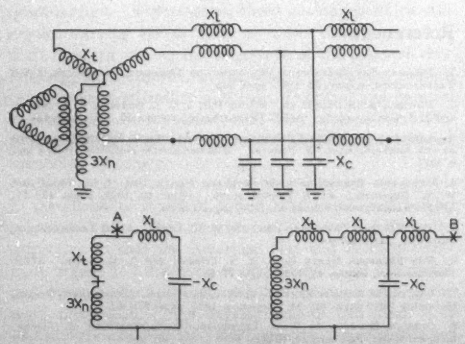
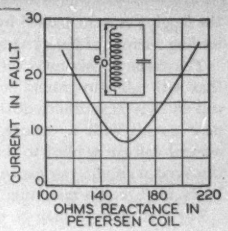


Figure 6. Zero-sequence impedance of Petersen-coil-equipped system with no ground fault

Figure 6A (lower left). Zero-sequence impedance for ground fault at (A)

Figure 6B (lower right). Zero-sequence impedance for ground fault at (B)

Figure 7. Tuning curve with one conductor grounded



circuit with a voltage applied to it resulting from the normal system unbalance in voltage as shown on figure 5. When the coil is in tune with the system, the inductive reactance of the coil balances the capacitive reactance of the system so that the current flowing is at a maximum and is limited only by the losses in the circuit. The current diminishes as the coil is detuned because the impedance of the resonant circuit increases.

For those familiar with symmetrical components, Petersen-coil action results when the zero-sequence impedance of a system is infinite. Accordingly, during ground faults, there will be no fault current in the positive- or negative-sequence impedance circuits and for calculations, the zero-sequence impedance circuit need only to be considered.

Tuning on normal unbalance in system voltage is expressed in symmetrical components by referring to the system zero-sequence impedance as represented on figure 6. Neglecting X_l and X_t which are small compared with X_n and $-X_c$ and designating the different capacitances to ground of the 3 phases as X_{c1}, X_{c2}, and X_{c3} the following equations may be written:

$$E + E_0 - I_{c1} X_{c1} = 0 \tag{1}$$

$$a^2E + E_0 - I_{c2}X_{c2} = 0 \tag{2}$$

$$aE + E_0 - I_{c3}X_{c3} = 0 \tag{3}$$

$$E_0 = -I_nX_n \tag{4}$$

$$I_n = -(I_{c1} + I_{c2} + I_{c3}) \tag{5}$$

$$I_n = \frac{E(X_{c2}X_{c3} + a^2X_{c1}X_{c3} + aX_{c1}X_{c2})}{-X_{c1}X_{c2}X_{c3} + X_n(X_{c2}X_{c3} + X_{c1}X_{c3} + X_{c1}X_{c2})} \tag{6}$$

tuning results when

$$X_n = \frac{X_{c1}X_{c2}X_{c3}}{X_{c2}X_{c3} + X_{c1}X_{c3} + X_{c1}X_{c2}} \tag{7}$$

When the capacitances of the 3 phases to ground are equal

$$X_n = \frac{1}{3} X_c \tag{8}$$

Tuning tests with one conductor solidly grounded are made by recording the current in the fault with the Petersen coil in different tap positions. The current in the fault is the resultant of the fundamental-frequency lagging current passed by the coil, and the leading charging current of the system, plus the in-phase components which result from leakage and harmonics. A typical plot of the fault current as a function of the ohms reactance in the coil is shown on figure 7. Correct tuning is obtained on the tap that results in minimum current in the fault as

the lagging current passed by the coil just neutralizes the leading current of the system.

The shape of this curve on figure 7 results from the fact that with a line-to-ground fault on a system, the Petersen coil and the capacitance of the system form a shunt resonant circuit with a voltage equal to the system line-to-neutral voltage applied to it as shown on figure 7. With this type of circuit, resonance is obtained when the current in the fault is at a minimum.

The fault current may be expressed as

$$I_f = \frac{E}{X_0} \tag{9}$$

For a fault at the terminals of the transformer in the neutral of which the Petersen coil is located (location A, figure 6A) the zero sequence impedance is equal to

$$X_0 = \frac{3X_n(X_l - X_c + X_l)}{3X_n + X_l + X_l - X_c} \tag{10}$$

Varying the magnitude of X_n, a curve is obtained such as is shown on figure 7.

In equation 10 neglecting X_l and X_l, resonance obtains when

$$X_n = \frac{1}{3} X_c \tag{11}$$

This shows that provided X_c is a constant, either method of tuning gives the same tap position for resonance as may be checked by comparing equations 8 and 11.

Corona has the effect of increasing the effective diameter of the line conductors which in turn increases the system capacitance and when corona is present, a lower ohmic setting will be obtained for correct tuning during solid ground faults. When corona is present, the results obtained from fault tuning rather than those from the normal leakage current through the coil should be used.

It has also been observed that the system capacitance changes slightly with changes in the weather. It is known that the apparent capacitance of pin insulators increases when they are wet or covered with sleet. In all cases noted, these changes have caused a shift of less than 5 per cent in the tuning so it has been of little practical significance.

Tuning is independent of fault location. A Petersen coil in tune to a system for a ground fault at any particular location is correctly tuned for a ground fault at any other location. For a ground fault at the terminals of the transformer of the system (location A) shown on figure 6 the zero-sequence impedance is as given by equation 10. For a ground fault at the far end of the system at location B, the zero-sequence impedance is (figure 6B)

$$X_0 = \frac{(-X_c)(3X_n + X_l + X_l)}{3X_n + X_l + X_l - X_c} + X_l \tag{12}$$

Correct tuning is obtained when X_0 is infinite. This occurs when the denominator of equations 10 and 12 are zero. Since the denominators of the 2 equations are alike, correct tuning in both cases is obtained.

It is to be noted that as the ground-fault location progresses away from the coil, the impedance increases and the current through the coil decreases. The charging current also decreases in like proportion so that correct tuning is always maintained.

The question often arises as to the accuracy needed in tuning a Petersen coil to a system. Field tests have shown repeatedly that the best results are obtained when the coil is adjusted to within a few per cent of the exact tuning necessary. However, on medium-voltage systems, successful arc extinction has been obtained through a relatively wide range in reactance in the coil. Field tests on several 33-kv systems have shown that successful arc extinction would still be obtained if 25 to 30 per cent of the system was switched out of service. On high-voltage lines, a somewhat closer tuning is indicated to be desirable.

Summary

Service experience with Petersen coils on transmission systems and networks in this country has demonstrated conclusively certain facts concerning these protective devices which may be stated as follows:

1. There is definitely a place for Petersen coils in American system-protective practice.
2. The Petersen coil will prevent the interruptions to service usually associated with transitory flashovers to ground.
3. The Petersen coil may be applied to any system insulated for full neutral displacement.
4. Petersen coils do not lose their effectiveness if used on a system when different sections are switched out of service unless the system capacitance is changed more than 25 to 30 per cent.
5. Surges during switching operations encountered on the first Petersen-coil application have not recurred in later applications.
6. By the use of Petersen coils, it is possible that from 70 to 80 per cent of all faults may be cleared without the opening of a single oil circuit breaker, and without any dip in the phase-to-phase voltage, thus improving system stability and service continuity.

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The Thyratron Motor at the Logan Plant

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Introductory

THE QUEST for a simple variable speed a-c motor has been long and, heretofore, not particularly successful. Consequently ever since the thyratron motor was mentioned during the early years of the present decade, it has aroused a great deal of interest among engineers, both because of its operating principles and because it appears to offer the possibility of a really effective and economical variable-speed alternating-current drive. It has been of particular interest to central-station engineers.

Quite a number of types of a-c drive are in use today in central station service and many more have been designed and discarded or never applied. The difficulties of the problem have not been ones of principle. On paper it may appear easy to develop such a drive having a minimum of special parts or a minimum assembly of standard units. Yet when these are tried in practice, some apparently insignificant detail—an oil ring or a rotating bearing—develops unexpected trouble during operation and definitely limits the new design. The squirrel-cage motor has set a criterion in ruggedness and simplicity that it has so far been impossible to equal.

In central-station service, the tendency has been to reduce to a minimum the number of auxiliaries requiring variable speed. In recent years studies of heat cycle, indicating the desirability of using steam turbines for the larger auxiliaries have further limited the use of variable speed motors. Nevertheless, those auxiliaries which still require varying speed, such as boiler feed pumps and draft fans, are among the largest, from the point of view of energy consumption, in the plant. They also require the utmost in reliability and ease of control and because they are often on practically a 24-hour basis of operation, it is desirable that variable speed be obtained without sacrificing efficiency.

The reasons for adopting this type of motor were given in the *Electrical World* of July 6, 1935, and need not be repeated here. The advantages appeared sufficiently attractive so that the American Gas and Electric Company urged the completion of developments on this motor and were in close contact with the manufacturer as the work progressed. In a development of this kind, it is particularly essential that the operating requirements are clearly brought to the attention of the designers. Their concentration on the theoretical aspects of the problem sometimes leads them to overlook homely but nevertheless important details. Dust tight distributor and tube compartments, safety interlocks on tube cells and cubicle doors, segregation of power and control terminals in the cubicle, forced air cooling, overspeed device, tube removal under load, and tube failure alarm are examples of the results of this co-operation. As in all new designs many minor difficulties arose which had to be overcome but nothing which could be considered basic.

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Description of Equipment

The motor is rated 400 horsepower, 2,300 volts, 3-phase, 60-cycles, 40 degrees centigrade and was designed to drive an induced draft fan having a speed range from 625 to 350 rpm. It closely resembles a standard synchronous motor with a rotating field, except that it has two independent star-connected stator windings installed in the same slots. Unlike a synchronous motor, however, the field terminals, after being brought out through slip rings, connect to the neutral points of the star windings. As shown in figure 4, the six remaining power leads connect in a special arrangement to a series of 18 type *FG*-118 thyratron tubes, each having a continuous rating of 12.5 amperes and a maximum rating of 75 amperes.

The accessory equipment includes a three-phase current-limiting reactor, a thyratron-tube cubicle, and a speed-

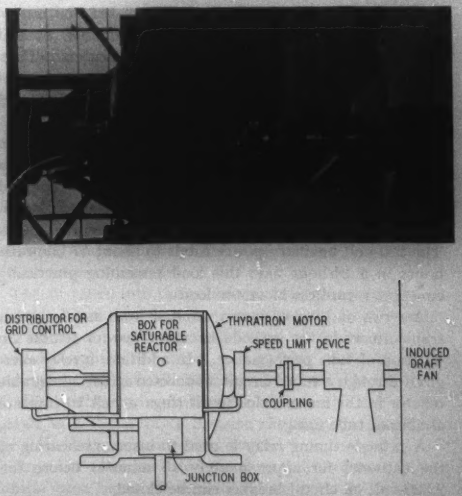

Figure 1. Thyratron-controlled 400-horsepower motor, Appalachian Electric Power Company—Logan plant

Figure 2. Thyratron cubicle showing spare tube compartment, Appalachian Electric Power Company —Logan plant

control panel. Each tube is mounted in an individual removable cell so as to facilitate replacement during operation. Tube cooling ducts and blowers, heater and grid transformers, and other accessories are all assembled within the cubicle.

The speed-control panel contains a small wound-rotor motor functioning as a phase shifter for the purpose of effecting the desired speed changes. On this panel are also mounted a line ammeter, the 2,300-volt primary oil circuit breaker control switch and the auxiliary power control switch. The motor, cubicle, and speed-control panel are shown in figures 1, 2, and 3 respectively.

Accessory Devices

The 18 thyratron tubes consume about three and one-half kw at full load with another one and one-half kw consumed in the various auxiliary transformers and relay coils in the cubicle. Forced air cooling is used to dissipate the tube losses. The air stream is directed at the base of the tubes and leaves at the top. For winter operation, the cooling system is operated partly closed and is supplemented by strip heaters. In the summer time it operates entirely open and without the heaters. Thermostatically controlled dampers regulate the output of the strip heaters as well as the proportion of recirculated and fresh air.

About 800 watts are consumed in excitation losses in the stator of the small wound-rotor motor which acts as a phase shifter for speed control, but since this is mounted on the speed-control panel which is remote from the cubicle, it does not contribute to the heat generated there. The 220-volt auxiliary power totals to about 57 kilowatt-hours in a 24-hour day, this load remaining practically constant regardless of motor load.

A series of 18 glow lamps, excited from small current transformers in the cathode circuits serve for remote indication of tube performance. In addition, a relay energized through a tuned circuit, connected across a saturable reactor in the motor field circuit rings a bell to indicate abnormal tube firing.

A cathode timing relay is used to insure preheating of the cathodes for approximately 15 minutes before the 2,300-volt oil circuit breaker can be closed.

Figure 5 shows the distributor which is mounted on the motor shaft to obtain commutation of energy between thyratron tubes. The distributor segments are connected to the grids through intermediate transformers. Two sets of segments are used, one for normal speed and a supplementary set effective at low speed by utilizing the inherent commutating action of the three-phase power supply to obtain a high starting torque. Transfer between sets is made automatically at about 150 rpm by means of a relay operating from a current transformer in the stator circuits.

An ingenious arrangement of current transformers is utilized to act on the grid circuits and cause a phase shift independently of the speed controller and thus limit tube current. Due to this feature the motor can be accelerated from standstill to a preset speed by throwing it directly across the line without danger of damage. It is thus inherently self-protecting, the overload relays on the oil circuit breaker acting solely as backup protection. Only twice rated full load current is taken under this condition.

For best operation the cathode heater potential should be lowered slightly as the load increases, since this tends to maintain a constant tube temperature. This is accomplished by inserting one winding of a saturable reactor in series with the heater circuit, the other winding being in series with the motor field. A third or saturating winding is excited from direct current. This saturable reactor serves a dual purpose, its other function being to initiate an alarm when a tube fails, as mentioned above.

Tube Disconnecting Feature

During the development of the control equipment it became evident that facilities would have to be provided for tube replacement while the motor was in operation. Since the anode potential is 2,300 volts, safety to personnel had to be taken into consideration. Means had also to be provided for interrupting the anode supply before the tube was removed and this required a 2,300-volt disconnecting switch capable of interrupting the normal tube current, since it was not considered advisable to interrupt

Figure 3. Speed-control panel for thyratron-controlled motor, Appalachian Electric Power Company—Logan plant

the anode circuit at the separable contacts of the individual tube cell. This presented a problem on account of the limited space available. It was successfully solved by developing the fuse type of disconnecting switch shown in figure 6*A*. The circuit is interrupted from the outside of the cubicle by the key which unlatches the door. The individual cells cannot ordinarily be unlocked without opening the respective disconnecting switch. However, when all tubes are to be inspected while the motor is out of service, a master key permits access to all of the cells without releasing the disconnecting switches. A thyratron tube with filament continuously heated is kept available at all times in a spare cell. (See figure 2).

Operating Principles

The operating principles of the motor have been fully described elsewhere (ELECTRICAL ENGINEERING, November 1934). For the sake of completeness a brief review with reference to figure 4 may be helpful.

The motor, although structurally resembling a synchronous machine, functions like a d-c series motor and has characteristics closely resembling such a machine. The field winding and each phase of each stator winding are traversed by a direct current, although like values of current in the stator coils differ in time phase.

A thyratron is a mercury-vapor hot-cathode rectifier tube. A positive grid voltage is essential to start the tube conducting, but once the current flows, the grid has no further effect and conduction will continue until the anode becomes negative with reference to the cathode. If the applied grid voltage is alternating, a shift in phase between the anode and grid voltages will delay the initiation of anode-current flow, decrease the amount of energy passed during the positive half cycle, and hence decrease the speed of the motor. From this it should be clear that the motor speed is independent of system frequency.

An open grid circuit will prevent tube conduction; therefore a distributor mounted on the motor shaft and connected into the grid circuits can control the time of firing of the tubes as a function of rotor position. Thus "commutation" can be attained. By connecting in parallel three tubes which receive their supply from a three-phase source, polyphase energy may be utilized for one stator phase subject to the control of the distributor. If the phase shifting and distributing features are connected in series, any tube can be controlled to fire at the proper time and for a desired interval. Thus commutation and controlled rectification with concomitant speed variation may be obtained within a single tube.

Figure 5. Distributor on thyratron - controlled motor, Appalachian Electric Power Company —Logan plant

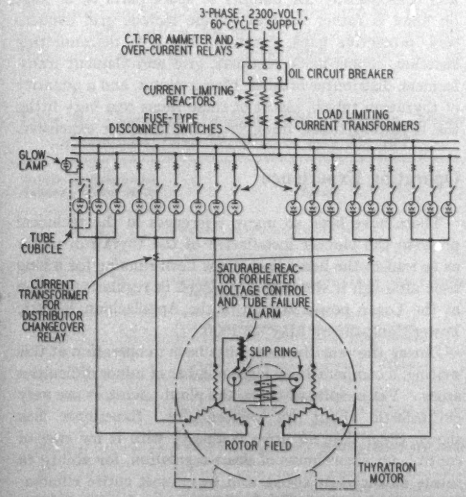

Figure 4. Power connections for thyratron-controlled motor, Appalachian Electric Power—Logan plant

Installation Considerations

Figure 7 shows a typical arrangement of connections between the motor and its control equipment. It is evident that there is an advantage in keeping the cubicle close to the motor. However, it is also necessary that it be installed in as cool a place as possible in order to limit the tube temperatures to the recommended upper limit of 55 degrees centigrade.

The air taken into the cubicle should be cool and clean as a deposit of dust may lessen creepage distance and lead to a failure of equipment. All covers in the cubicle must be sealed tightly to prevent dust gaining access to parts having inherently small clearance to ground. At the time of this writing it is planned to relocate the cubicle at Logan to a cooler place because the tube temperatures are close to the recommended limit.

Experience has indicated the desirability of having the cubicle base mounted on resilient supports in order to minimize shock. Rubber mounting pads under the four corners are being used for this purpose.

Since the motor has characteristics similar to a d-c series motor, precautions against loss of load, however remote, must be taken and a speed-limit device interlocked with the primary breaker control should be installed. An additional safeguard is provided in a limit stop which is placed on the speed control dial so that the rated speed cannot be exceeded. (See figure 3.)

The saturable reactor previously described is mounted directly on the motor frame and enclosed in a sheet metal box, thus avoiding the use of additional high voltage power connections. It is recommended that the distributor selector relay be also mounted in this cabinet, thus materially lessening the number of control wires between the motor and cubicle.

Spare Parts

Since there are 18 duplicate tubes with their accessories, the number of different types of device is not very large and consequently the number of spare parts to be kept on hand is rather limited. These include grid condensers, protective gaps, resistors, fuse-type disconnecting switches, copper-oxide rectifiers, grid and filament transformers, distributor brushes, blower motor, and a quantity of thyratron tubes. Most of these items cost very little; the thyratron tubes, however, are still rather expensive.

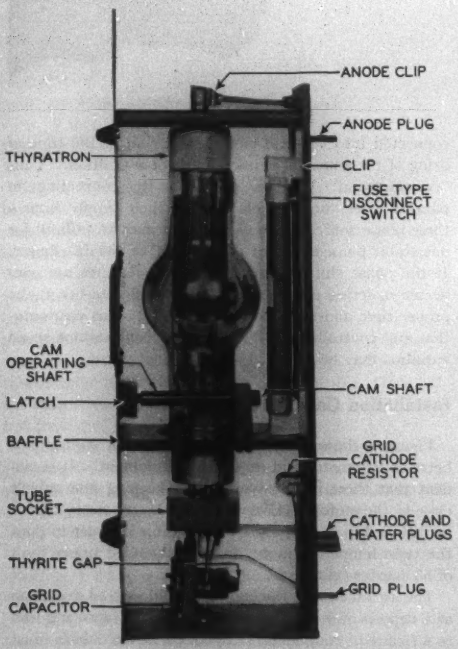

Figure 6. Thyratron tube cell showing 2,300-volt fuse-type disconnect switch

The door latch rotates the eccentric thus releasing pressure on a flat copper contact strip. The spring retracts the conductor through a section of fuse powder, thereby breaking the circuit. This switch can be used indefinitely since the conductor does not ordinarily fuse—only a slight pitting appears at its tip after a number of operations. To recondition, an operation similar to refilling a standard fuse is required, taking only a few minutes

Table I. Thyratron Tube Failures, May 29, 1936 to July 31, 1937

Failure Number	Tube Service Hours of Operation	Time of Failure	Nature of Failure
1	191	While starting	Cathode heater burned open
2	679	While starting	Cathode heater burned open
3	787	While starting	Cathode heater burned open
4	1,079	During preliminary heating before starting	Cathode heater burned open
5	2,362	During preliminary heating before starting	Cathode heater burned open
6	2,862	While starting	Cathode heater burned open
7	792	During preliminary heating before starting	Grid destroyed Cathode heater burned open
8	3,576	During operation	Apparent short circuit in tube. Protective gap and capacitor destroyed
9	4,509	During operation	Cathode heater burned open
10	4,628	During preliminary heating before starting	Cathode heater burned open
11	5,440	During operation	Tube ceased firing for no apparent cause
12	5,829	During preliminary heating before starting	Cathode heater burned open
13	5,829	While starting	Tube ceased firing for no apparent cause
14	3,550	During operation	Tube ceased firing for no apparent cause
15	6,400	During operation	Cathode heater burned open
16	742	During preliminary heating before starting	Cathode heater burned open
17	7,106	During operation	Cathode heater burned open
18	2,053	During operation	Interior of tube completely destroyed
19	7,560	During operation	Tube ceased firing for no apparent cause
20	8,272	During operation	Cathode heater burned open

Operating Experience

There have been so many references in the technical press to the pioneer installation of the thyratron motor as to lead to the belief that it has been running for a long time although it was actually placed in regular operation at the Logan power station of the Appalachian Electric Power Company on May 29, 1936.

During the year the motor has been in operation at this writing, a comparatively large number of minor difficulties arose. Yet in spite of these, the plant operators are very enthusiastic about its performance. Experience has shown them that no drive compares with it for ease of control, for smoothness of draft regulation, for ability to rotate at very low speed, and for almost entire elimination of fan blade maintenance expense. In view of the fact that plant operators are pretty hard-headed and tend to look with suspicion on new "gadgets," this response

would seem convincing evidence of its success from a practical standpoint.

The most serious difficulty has been with the thyratron tubes themselves. In 14 months of operation, 20 tubes have failed, almost all of them due to the opening of the cathode heater circuit. Table I summarizes these failures and table II troubles from other causes. It is to be noted that the actual hours of motor operation represent a service availability of 84 per cent. This includes shutdown from all causes such as boiler and fan maintenance. Interruptions due to the motor alone took only three and one-half per cent of the operating time and an availability of 93½ per cent may be considered a not unsatisfactory record for an entirely new type of control.

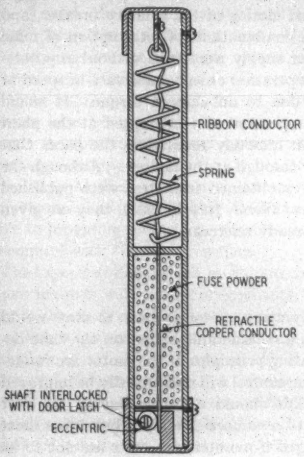

Figure 6A. 2,300-volt fuse-type disconnect switch for thyratron - controlled motor

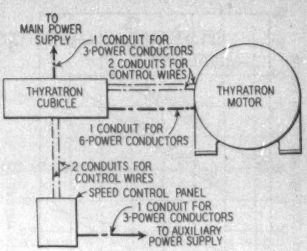
TO MAIN POWER SUPPLY
1 CONDUIT FOR 3-POWER CONDUCTORS
2 CONDUITS FOR CONTROL WIRES
THYRATRON CUBICLE
THYRATRON MOTOR
1 CONDUIT FOR 6-POWER CONDUCTORS
2 CONDUITS FOR CONTROL WIRES
SPEED CONTROL PANEL
1 CONDUIT FOR 3-POWER CONDUCTORS
TO AUXILIARY POWER SUPPLY

Figure 7. Thyratron - controlled motor—typical arrangement of equipment and conduits

Table II. Operating Troubles With Thyratron Motor Accessories, May 29, 1936 to July 31, 1937

Failure Number	Interruption Time—Hours	Cause
1		Filament transformer burned out
2	192	Field coil burned out
3	84	Field coil burned out
4	½	Fuse type disconnect switch burned open
5	20	Ground on one stator phase due to cable rubbing against dowel pin
6		Fuse type disconnect switch pulled apart
7	1½	Protective gap and grid capacitor destroyed
8	½	Thyratron tube and protective gap destroyed
9	3½	Fuse type disconnect switch arced to ground. Replaced. Again arced to ground. Replaced
10	4	Ventilating fan motor burned out
11		Field coil showed evidence of charring
12		During boiler shutdown, new set of field coils installed, and bearings changed
13		Fuse type disconnect switch burned open
14		3 tubes fired irregularly. Brush on distributor made poor contact
15		Bearings worn due to erratic magnetic center Evidence of electrolysis causing bearing pitting. Corrected by placing brushes in contact with both ends of shaft, connecting together and grounding

Total: 306 boiler-hours lost.
Total hours of operation: 8,376.

Discussion of Operating Troubles

Many of the difficulties encountered are of a nature which would make it extremely improbable that they will be encountered again. For instance the trouble with three field coils was evidence that the motor field was being subjected to unexpected surge voltages and that its original insulation was inadequate. When the entire set of coils was replaced by ones having greater insulation, no further trouble of this type manifested itself.

The pitting of the bearings and the unexpected thrust due to unbalanced magnetic forces causing excessive bearing lining wear and coupling troubles were completely cured by the installation of brushes bearing on the shaft and connected to ground.

Failure of parts due to arcing to ground have been corrected where possible by providing greater clearance and the experience gained from this can of course be incorporated in subsequent designs. The fuse-type disconnect switches leave some room for improvement but they were an afterthought in the initial installation and probably a better type of device will be available for subsequent installations.

The grounding of a stator phase lead by rubbing against a metal dowel pin could have occurred in any machine.

Auxiliary transformers, protective gaps, resistors, condensers, blower motors, etc., are always possible sources of trouble. Filament and grid transformers operate at 2,300 volts and clearances must be kept large to avoid creepage due to infiltration of conducting dust which is always present in a power plant. No doubt some of the smaller devices will occasionally fail from time to time, but they are comparatively inexpensive to replace and mostly of such a nature as not to cause an immediate shutdown in case of failure. Even these can be improved by careful attention to the requirements.

The thyratron tubes leave the biggest room for improvement. A large number of failures has resulted either while starting or during the preliminary heating period and tube designers should consider these facts. Without a doubt the fragility of the cathode heaters can be corrected. The very persistance of this type of failure should be a clue to the remedial measures necessary. Steps have already been taken in this direction by the use

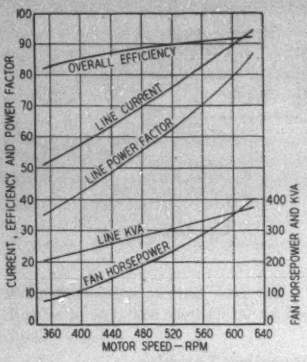

Figure 8. Performance characteristics of thyratron motor as determined by test

of flexible instead of solid connections at the cathode heater terminals within the tube.

Operation With Defective Tubes

Although defective tubes are replaced almost immediately during operation, it is interesting to note that no harmful effects occur if several tubes cease firing simultaneously. During factory tests as many as four tubes were removed simultaneously in various combinations, from different parts of the circuit, the only noticeable effect being a drop in speed and a slight irregularity in rotation. The motor will even start single phase (six tubes removed) although, of course, it will not attain full speed under this condition.

Tests were made with the cathode heater supply and grid control circuits suddenly interrupted to simulate blowing of fuses. Speed remained normal during the 15-second interval permitted by the cathode timing relay before shuttting down the motor. Low primary voltage, sudden opening and closing of the primary breaker, and almost all possible combinations of interruption of main and auxiliary power supply were tried without any noteworthy change in operation except a decrease in speed or irregular rotation due to unbalanced torque. It would go hard with any operator who attempted at the plant any operation even remotely resembling the paces that the motor was put through at the factory. Although the characteristic curves obtained from test were published previously (*Electrical World*, July 6, 1935), they are given here (figure 8) for ready reference.

Conclusion

Whether the thyratron motor is here to stay would seem to depend to a considerable extent on the tube designer. The operating principles of the motor are fundamentally sound; the control will undoubtedly be improved and simplified. This should aid in reducing the first cost of the motor to a competitive level, but tubes must be made more rugged if maintenance costs are not to be excessive.

A New Single-Channel Carrier Telephone System

By H. J. FISHER
Membership Application Pending

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ON OPEN-WIRE lines where the growth is not rapid, there is frequently need for adding telephone circuits one at a time. When the type-*D* single-channel carrier telephone system was developed a few years ago it became possible to meet this need without stringing additional wires.[1] More than 500 of these systems have been placed in service in the Bell System plant. A new single-channel carrier telephone system, known as the type *H*, has recently been developed and is now being applied. This new system offers improved performance, and also, because of its lower cost, is applicable to providing service over shorter distances than were economical with the earlier system.

The type-*H* system, which is characterized by a number of new features and special developments, is applicable not only to the needs of telephone companies but also to those of railroads, power systems, and oil companies.[2] In the first place it is designed to operate either on a-c or on d-c plate and filament supply. A repeater is available to extend the range of operation. Through the use of specially designed but simple filters the system can be employed on circuits which are equipped with bridged telephone stations at intermediate points as is frequently the case in railroad operation.

A unique feature is the use of opposite sidebands of the same carrier frequency for opposite directions of transmission. The upper sideband is used in one direction and the lower sideband in the other, the carrier being suppressed. For the modulators and demodulators copper-oxide "varistors" are employed in place of vacuum tubes. The amplifiers are single stage, employ pentode tubes and are stabilized in performance by feedback. The filters are simplified in construction by the use of coils with a new type of core material and by improved designs of paper condensers.

The size of the new terminal has been so reduced that it occupies less than 40 per cent of the space required for a type-*D* terminal, as indicated in figure 1. The equipment may be mounted on racks as is customary in telephone offices, or a complete terminal or repeater may be mounted in a small cabinet.

Single-channel carrier systems have been used in the Bell System principally for short open-wire toll circuits. Thus, the type *D* systems are for the most part between 50 and 200 miles in length. The type-*H* system, since it includes a repeater can be used for greater distances, and due to its lower cost is economical for shorter distances.

General Description of System

Basic System

The basic system consists of two terminals one of which is refered to as an "east" terminal and the other as a "west" terminal, as indicated in figure 2. The two terminals differ only in minor respects, the differences being due to the fact that at one terminal the upper sideband is transmitted and the lower sideband is received, while at the other terminal the reverse takes place. In order to simplify co-ordination between various types of carrier systems operating on the same pole line, the frequencies between 7,400 and 10,150 cycles are transmitted in the east to west (or north to south) direction, and the fre-

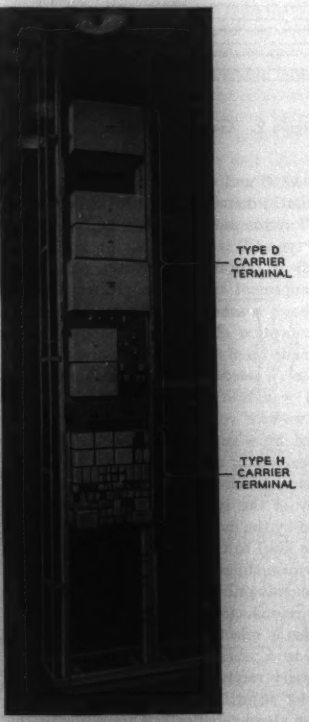

Figure 1. Installation of type-H carrier telephone system at Charlotte, N. C.

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1. For all numbered references, see list at end of paper.

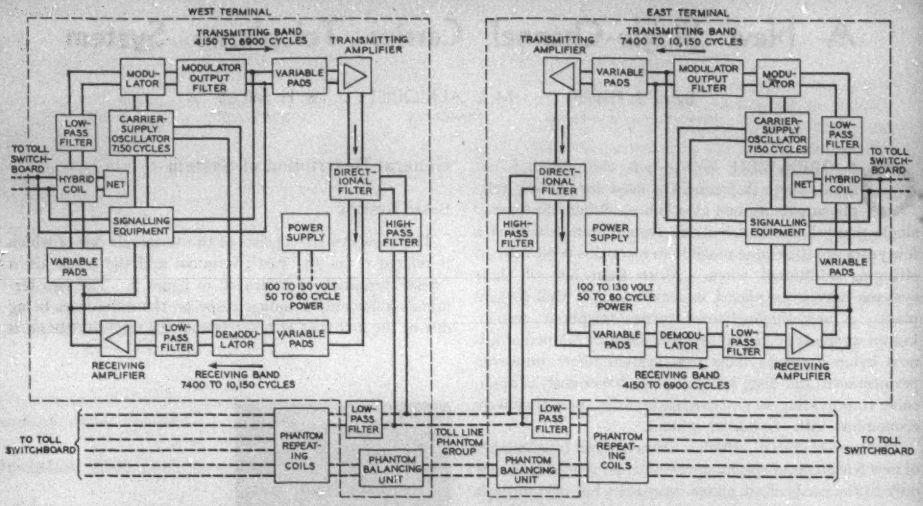

Figure 2. General schematic of type-H system applied to side circuit of phantom group

quencies between 4,150 and 6,900 cycles in the west to east (or south to north) direction. The frequency allocation of the type *H* system and those for the type-*D* and the three-channel type-*CS* system are shown in figure 3. All three types may be operated on the same pole line.

The circuit arrangement is given in greater detail in figure 4, which shows a schematic diagram of one terminal, with the exception of the power supply circuit. Each terminal is made up of a transmitting branch which includes a modulator, a receiving branch which includes a demodulator, and a hybrid coil to combine the two branches into a two-wire voice frequency circuit. The carrier is generated by a vacuum tube oscillator which supplies both the modulator and demodulator. The output of the modulator, which is of the copper-oxide type, consists principally of the two sidebands. The desired sideband is selected by the modulator output filter and an amplifier raises the level to that desired for transmission over the line. The demodulator is also of the copper-oxide type; its output consists principally of the two sidebands, one of which is a reproduction of the original voice-frequency input. This is selected by means of a low-pass filter and applied to a voice-frequency amplifier which provides the necessary receiving gain. Adjustable pads serve as a means for adjusting the transmitting and receiving gains. The characteristics and functions of the various filters are described later.

For signaling over the carrier circuit, a 1,000-cycle signaling system is employed. The method is similar to that used on other types of circuits, but includes a number of simplifications. The number of tubes has been reduced, and the vibrating relays used in the older type circuits have been replaced by copper oxide rectifiers and simple d-c relays requiring little maintenance. When 20-cycle ringing current is received from the switchboard the frequency of the carrier supply oscillator is shifted by 1,000 cycles and its output is interrupted at a 20-cycle rate, and applied to the input of the transmitting amplifier. At the receiving end this appears at the input of the signal receiving circuit as a 1,000-cycle current interrupted at a 20-cycle rate. It is then demodulated in a copper-oxide rectifier and the resulting 20-cycle current is amplified and applied to a second rectifier the output of which is connected to a d-c relay. Operation of this relay causes 20-cycle current from a local source to be sent toward the switchboard. Freedom from false operation on speech is obtained by tuning the receiving circuit to the rate of interruption and by providing a slow operating relay such that the signal must persist for several tenths of a second before 20-cycle current is passed to the switchboard.

The power supply circuit, which is shown in figure 5, operates from an a-c source of 100 to 130 volts, 50 to 60 cycles and requires about 50 watts. It supplies a-c for the filament supply, 160 volts d-c for plate supply and 24 volts d-c for relay operation. Provision is also made for direct operation from 24-volt and 130-volt central office batteries.

The equipment for a terminal is mounted on two panels. One of these, shown in figure 6, is $15\frac{1}{4}$ inches by 19 inches in size and contains all the apparatus except the line filter circuit. The second panel, shown in figure 7, is $3\frac{1}{2}$ inches by 19 inches and contains the line filters, and other equipment which is required for balancing purposes.

Repeater

A schematic of the repeater is shown in figure 8. The amplifiers are the same in design as the transmitting

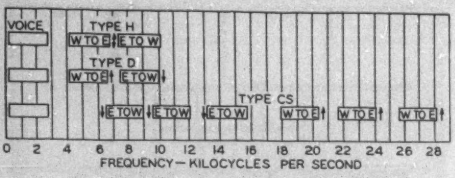

Figure 3. Frequency allocation

amplifier at the terminals. Two sets of line filters are required, and are identical with those used at the terminals. The a-c power supply circuit is substantially the same as the one used at the terminals except that the 24-volt supply for relay operation is omitted. The power required for operation is about 35 watts.

The complete repeater consists of three panels—the repeater panel, which is $10^1/_2$ inches by 19 inches, and two line filter and balancing panels. The repeater panel is shown in figure 9.

Transmission Performance

Line Considerations

In outlining the transmission performance of the system, it is necessary to consider the characteristics of the lines as well as those of the equipment. At carrier frequencies the line losses and the variations in these losses with weather are considerably greater than at voice frequencies. This is illustrated in figure 10 which shows the attenuation-frequency characteristics for four commonly employed gauges of open-wire line under dry and wet weather conditions, respectively, at a temperature of 68 degrees Fahrenheit. These curves are for 12-inch spaced copper wires equipped with the type of insulators ordinarily employed for toll circuits. Changes in temperature also affect the attenuation, the loss increasing as the temperature rises. The variations due to changes in temperature are, however, smaller than those due to changes from dry to wet weather and are more likely to occur gradually. It is apparent that the variations in attenuation with weather increase with the length of the system, and that more frequent adjustments will be required on the longer systems to maintain the over-all circuit net loss within given limits.

The carrier frequency attenuation of cable circuits is much greater per unit length than that for open-wire lines. Hence, the losses introduced by comparatively short sections of cable, either at entrances to offices or at intermediate points are of considerable importance. In addition to the attenuation of the cable itself, there are large reflection losses at the junction of the cable and the open wire, due to the difference between the characteristic impedance of the open wire and that of the non-loaded cable. The carrier terminal and repeater have been designed to have the same impedance as the average of the open-wire line facilities, so the same considerations apply

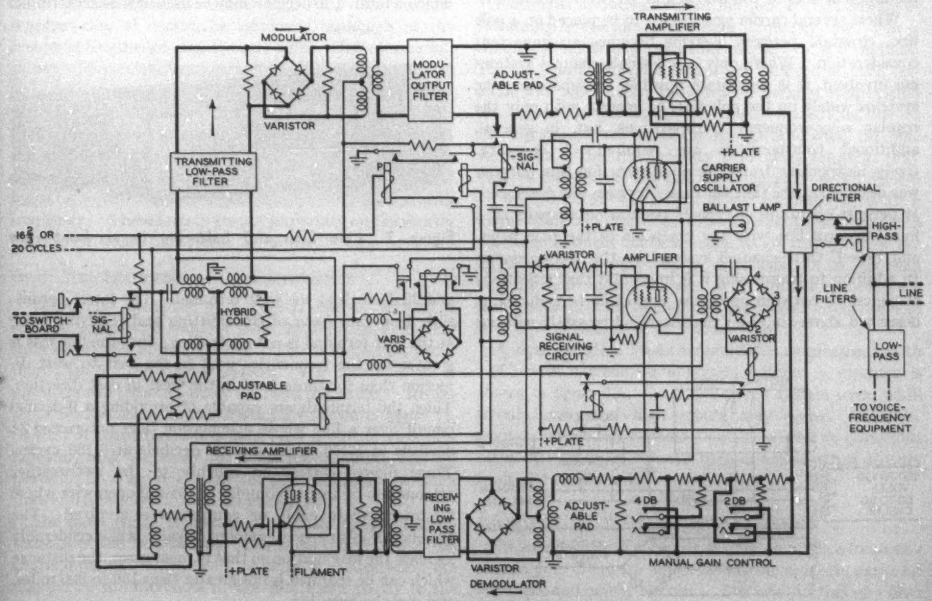

Figure 4. Schematic of type-H terminal

at the junction of the cable and the carrier equipment. As an example of the magnitude of these effects, the insertion loss at 8,000 cycles of two miles of non-loaded 16-gauge cable is approximately 6 decibels, or about the same as that of 60 miles of 104-mil open wire.

By applying carrier loading that has been developed for this purpose, the attenuation loss of such a cable can be reduced to about one decibel at 8,000 cycles. In addition, the reflections at the terminals of the cable will be reduced to satisfactory low values by virtue of the impedance matching properties of the loading. This method of treatment has the important advantage that it improves the transmission characteristics in both the voice and carrier range.

In cases where substantial transmission margins exist, it is sometimes practicable to use impedance matching transformer networks at the cable terminals, as a substitute for carrier loading, with economies that are proportional to the length of the cables. At the present stage of development, this so-called transformer treatment is much less satisfactory in the voice-frequency range than in the carrier-frequency range. Certain inherent limitations in simple transformer treatment result from the fact that the ratio of the (non-loaded) cable impedance to the open-wire impedance varies widely over the frequency band to be transmitted, and the transformer impedance ratio that is optimum at carrier frequencies is distinctly disadvantageous in the voice frequency range. The choice of optimum transformer ratio for the complete transmission band may thus involve different compromises for different sets of conditions and service requirements.

Where several carrier systems are to be placed on a pole line, crosstalk between systems becomes an important consideration. Where only a few single-channel systems are involved, it is sometimes possible, by separating the systems widely on the pole line, to operate with only the regular voice-frequency transpositions, but, in general, additional transpositions are required. A comparatively inexpensive transposition system for this purpose was designed at the time the type-*D* system was developed. It permits operation of type-*H* systems on all pairs of a four crossarm line with the exception of the pole pairs, and type-*C* three-channel systems on the top crossarm. In addition to transposing it is important that reflections at junctions between open-wire and cable be reduced as described above, in order that near-end crosstalk will not through reflection appear as crosstalk at the distant terminal of the system.

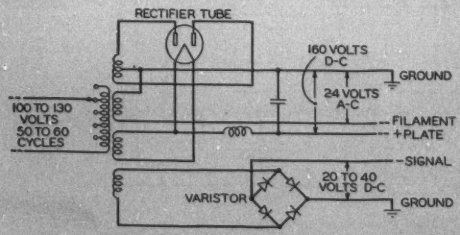

Figure 5. Schematic of a-c power supply for terminal

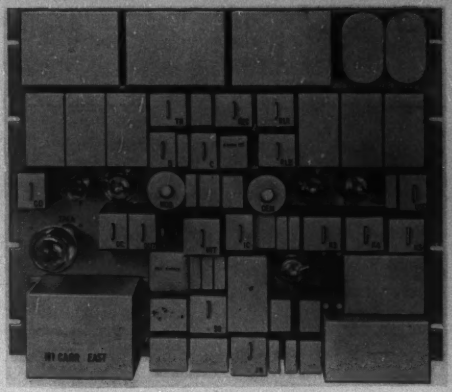

Figure 6. Terminal panel—front view

Range of Operation

The terminals and repeaters have sufficient load carrying capacity so that they may be operated at an output level 16 decibels above that at the transmitting toll switchboard. About 19 decibels transmitting gain and 14 decibels receiving gain are available at each terminal, of which a total of 20 decibels may be used at the east terminal

Figure 7. Line filter and balancing panel—front view

and 22 decibels at the west terminal. The lower permissible loop gain (sum of transmitting and receiving gain) at the east terminal is not controlling, since the line loss is greater for the frequencies used in the east to west direction than for those used in the west to east direction. Thus, the terminals are capable of providing a 9-decibel circuit over a line whose attenuation does not exceed 31 decibels at 8,150 cycles and 29 decibels at 6,150 cycles. These figures correspond roughly to the wet-weather attenuation of about 280 miles of 104-mil open wire where no intermediate cable or equipment is involved. The presence of even a small amount of cable will considerably increase the attenuation so that in most cases, the distance which can be spanned is not greater than 150 to 200 miles, and may be even less.

Where greater distances are to be covered, an inter-

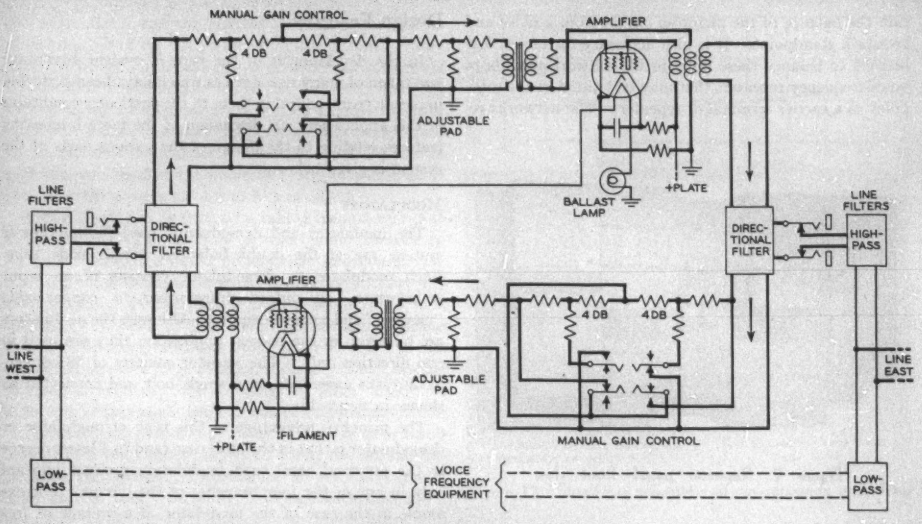

Figure 8. Schematic of repeater

mediate repeater may be added. The repeater has a useful gain of about 23 decibels in each direction, with some flexibility as to allocation of gains between the two directions of transmission. More than one intermediate repeater can, of course, be employed, although as the system is lengthened maintenance effort will be increased, as more frequent adjustments of the over-all net loss will be required to compensate for the variations in line attenuation with weather. No provision is made for a pilot channel such as is generally provided on the long multichannel systems, and adjustments of over-all net loss must be made manually. Also, no provision has been made for equalizing the variation in line attenuation with frequency. These factors are not important on the shorter circuits for which the system has primarily been designed.

Over-All Transmission Characteristics

The circuit provided by a type-*H* system without a repeater has a band width of about 2,750 cycles, extending from about 250 to 3,000 cycles. This is somewhat wider than that for the type-*D* system. The introduction of repeaters will tend to narrow the band somewhat. Representative frequency characteristics are shown in figure 11. One set of characteristics is for a typical circuit without a repeater, and the other for a circuit including two repeaters. It is assumed that the line conditions are such that no large reflection effects are present.

The band width is limited principally by the characteristics of the band filters. The small differences in the characteristics for the two directions of transmission are due partly to differences in the filters and partly to the fact that the attenuation of the line increases with frequency and is greater at the 3,000-cycle point in the east-to-west channel than for the 3,000-cycle point of the west-to-east channel. As the circuit is increased in length this difference tends to increase.

Variations in over-all circuit net loss are due largely to variations in the loss of the high frequency line. For a circuit 200 miles long these may amount to ± 3 decibels. The key-controlled pads which are included at each terminal and repeater are provided for making adjustments to compensate for these variations. Variations due to the equipment are small in comparison with the line variations. The transmitting gain at a terminal may vary ± 0.5 decibel and the receiving gain ± 0.3 decibel for variations of ± 10 volts in the a-c supply. With a more stable a-c supply or when operated from regulated plate and filament batteries such as are employed in the larger telephone offices, these variations will be less than half the figures given above. With suitable maintenance it should be possible to maintain the over-all circuit net loss within ± 2 decibels of its normal value.

A representative load characteristic, as measured with 1,000-cycle current for a system without a repeater is shown in figure 12. On a repeatered system some additional limiting of high inputs may occur. However, even on repeatered systems, there should be no noticeable distortion for input volumes such as are obtained directly from a switchboard.

Reactions on Voice-Frequency Circuit

In superimposing a carrier system on a voice-frequency circuit, line filters are added to provide separate paths for the voice and carrier circuits. The introduction of a filter in one side of a phantom group requires the addition of a network in the other side of the phantom group to main-

tain the balance of the phantom circuit from a noise and crosstalk standpoint. It is also necessary for return loss reasons to balance these units in the network circuits of voice-frequency repeaters that may be located at the same point as a carrier terminal or repeater. The networks required to take care of these conditions are included with the carrier system.

Figure 9. Repeater panel—front view

In some cases it is desired to apply the type-*H* system to circuits equipped with bridged telephone stations at intermediate points. Such arrangements are common on railroad communication systems, and occur to a small extent in the Bell System. In such cases, excessive interference into the carrier system due to talking at the way station, and into the way stations due to talking on the carrier system, is likely to occur unless suitable filters are provided at each way station. A simple filter for this purpose has been developed for use with the 501-type subscribers set, and work is proceeding on a similar filter for use with other types of subscribers sets.

The line filters and the filters for use at way telephone stations each introduce a loss of about 0.15 decibel to the through voice-frequency transmission. Where the voice-frequency circuit is equipped with repeaters and return loss conditions permit, these additional losses may be taken care of by readjusting the voice-frequency repeater gains. In extreme cases, particularly where a considerable number of filters are to be added, it may be necessary to resort to other means of improving the transmission on the voice-frequency circuit, such as loading of incidental cables or the addition of a voice-frequency repeater.

On circuits equipped with way stations, selective signaling by means of selectors is sometimes used. Such signaling systems are generally arranged to apply an "answer back" tone to the line when a station has been called to indicate to the calling party that the selector has operated. This tone contains a considerable amount of high-frequency currents so that it is necessary to modify the selector circuit to filter out the high frequencies. The modification is a simple one and makes the answer back tone inaudible on the carrier circuit.

Design Features

In the development of the type-*H* system advantage was taken of many new devices which have been perfected in recent years, adapting them to the particular conditions of this application. A discussion of the more interesting features relating to the design of the various parts of the system is given below.

Modulators

The modulator and demodulator used in the type-*H* system are of the double-balanced copper-oxide type. Each modulator or demodulator consists of an input transformer, an output transformer, a copper-oxide "varistor" and a carrier supply. Although the modulators are bilateral, in the present application they are used in one direction only. The varistor consists of 48 copper-oxide disks assembled on a single bolt and connected as shown in figure 13.

The principal advantage of this type of modulator or demodulator is that in the ideal case (and to a lesser degree in the practical case) each modulation product appears only in one of the four branches of the circuit. For example in the case of the modulator, if a voltage of frequency V is applied to the input and a voltage of frequency C is applied by the carrier supply circuit, resulting products of modulation will appear in the ideal case as shown in figure 13. It is obvious that the only unwanted products in the output which cannot be suppressed by filters or balance are those which are of the frequency $(C \pm AV)$ which for some values of A and V fall in the frequency range of the desired sideband $(C + V)$ or $(C - V)$.

These components, however, are normally more than 50 decibels weaker than the sideband and are not noticeable. Of course, the term AV represents not only odd harmonics of V but odd order intermodulation products such as

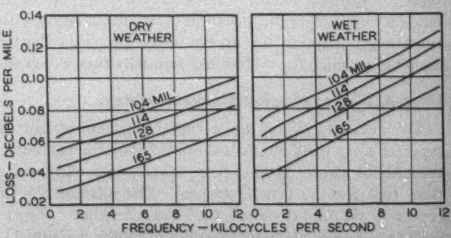

Figure 10. Attenuation of open-wire side circuits, 12-inch spaced copper wire with double-petticoat glass insulators

$(2V_1 \pm V_2)$. The relative amplitudes of the $(C \pm AV)$ terms increase with load in a similar manner to that for the distortion products of an amplifier as the overload point is approached, and the effect on articulation is the same.

For the actual case the modulator balance is not perfect

and all products and the original frequencies do appear in all branches of the circuit including the output. However, the balance in most cases is greater than 30 decibels and the filter requirements are helped to that extent over some portions of the frequency range. This is particularly helpful in connection with suppressing the carrier from the output and input since it lies only about 200 cycles from the pass band and it would be costly to obtain all of the suppression required by means of filters.

With a single disk in each arm, taking the factory run of disks and making no attempt to select units the balance for many assemblies would be less than 15 decibels. By selecting units, this balance could be improved to any desired amount. In the present design, however, to save the cost of selection 12 disks were used per arm to obtain the better balance resulting from the averaging of the characteristics of a large number of disks. There is some sacrifice in efficiency due to using the large number of disks but in this application it was of minor importance.

The averaging obtained by using 12 disks in each arm is helpful in several other respects. First, the normal impedance, transmission, and balance do not vary greatly from unit to unit. Secondly, although each disk has a negative coefficient of resistance vs. temperature and there is a variation in the coefficient among disks, the average coefficient of 12 disks chosen at random will be very nearly equal to the average of any other 12 disks chosen at ramdom and the balance between arms will, therefore, remain practically constant with temperature, even though the impedance and efficiency vary. A similar advantage is obtained in the case of aging and a good balance is obtained throughout the life of the equipment.

Oscillator

As mentioned previously the same carrier (suppressed) frequency is used for transmission in both directions, thus requiring a single oscillator instead of two as in the type-*D* system. The principal requirement for an oscillator for this use is that its frequency remain stable under the variations in power supply voltage and temperature which will occur. The new design which is shown schematically in figure 14, provides a degree of stability such that no operating adjustments will be required due to these factors. Relatively high stability with changes in temperature is obtained by balancing the positive capacitance-temperature coefficient of the copper-oxide load and the mica tuning condenser against the negative coefficient of the paper tuning condenser.

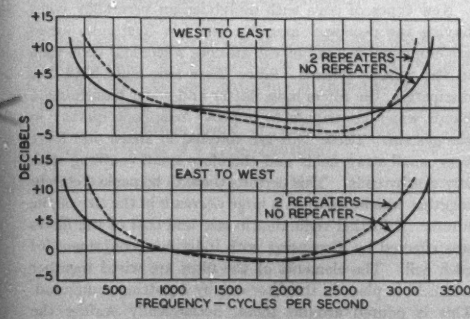

Figure 11. Representative over-all circuit net loss characteristic of system

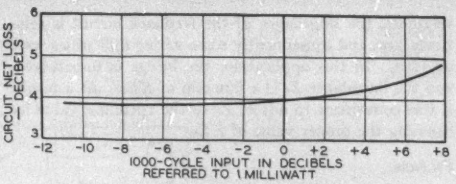

Figure 12. Representative system load characteristic

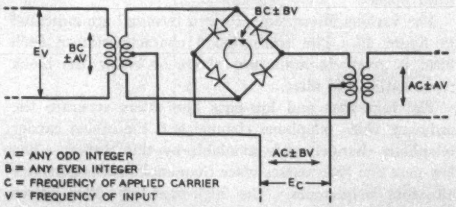

Figure 13. Simplified schematic of copper-oxide modulator

The stability of frequency with plate voltage variations is about $5/10^8$ parts per volt. This is adequate and was obtained without the use of an expensive tuning inductance. The coil used, which also serves as output and feedback transformer has a ratio of reactance to resistance of about 20 and is an air-core solenoid potted in a copper can.

Amplifiers

Both the receiving and transmitting amplifiers employ a single pentode with about 9 decibels feedback. For this amount of feedback, the variations of gain and impedance due to power supply variations are reduced to at least one-third of the amount of the variation obtained without feedback, and the load carrying capacity is increased about one decibel.

The two amplifiers differ in that the frequency range transmitted is different and in that the output transformer of the receiving amplifier also acts as an inequality ratio hybrid coil to separate the receiving signaling circuit from the two-wire voice circuit. The two circuits are shown in figure 4. In each case, the feedback is accomplished by means of a bridge circuit in the output and a series connection in the input. This can be more readily seen from figure 15, which is a simplified circuit representing both amplifiers. There is a considerable saving in circuit elements as compared to the familiar resistance bridge feedback connection. The output power loss due to shunt arms of the resistance bridge is eliminated. Fur-

thermore, the impedance of the feedback circuit is relatively low, and consequently some wiring difficulties were avoided. In this application, the bridge is unbalanced, and the impedance Z_0 is a function of KR_0. As a result, it was convenient to adjust Z_0 to the optimum value by choosing the proper value of KR_0.

Filters

Filters constitute an important part of the type-*H* carrier system. They represent about 30 per cent of the cost of the terminal and occupy about 25 per cent of the total space.

The various filters required at a terminal are indicated in figure 16. The transmission characteristic of each filter is given in miniature above or below the block representing the filter.

The high-pass and low-pass line filters separate the ordinary voice telephone channel and the added carrier telephone channel made available by this system. The low-pass line filter passes voice frequencies and suppresses all other frequencies. The high-pass line filter passes the carrier frequencies and suppresses the voice frequencies. Each filter offers a high impedance to the frequencies passed by the other, and bridges off only a very small part of the energy of these frequencies.

The remaining filters are associated with the carrier terminal proper, where they serve to separate the transmitting and receiving paths and suppress unwanted frequencies. The voice frequencies pass through the hybrid

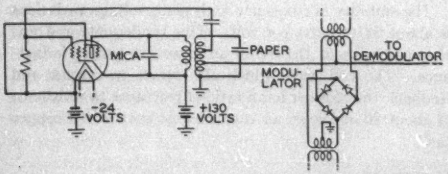

Figure 14. Schematic diagram of oscillator circuit

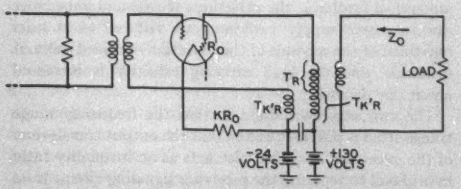

Figure 15. Simplified schematic of amplifier

coil and the transmitting low pass filter to the modulator. This filter limits the path between the hybrid coil and the modulator to voice frequencies only. Modulation of the voice with the carrier frequency of 7.15 kilocycles produces two sidebands extending from 4.15 to 6.90 kilocycles and from 7.40 to 10.15 kilocycles. At an east terminal, the upper sideband is transmitted, and the modulator output filter passes this sideband and suppresses the lower sideband, together with other unwanted modulation products. In this manner it limits the load on the amplifier to the desired sideband. The transmitting directional filter offers further suppression to frequencies lying outside this band. The receiving directional filter will not pass this band but has a high impedance to these frequencies. The high-pass line filter passes all frequencies above roughly 3.5 kilocycles and, therefore, this band passes through it readily and out onto the line for transmission to the distant terminal. Transmission from a west terminal is identical in principle but here the lower sideband is passed by the modulator output filter and transmitting directional filter while the upper sideband is suppressed.

It is apparent from figure 16 that the received sideband coming in on the line from the distant repeater or terminal is operated upon by the filters in a reverse manner from that described above for the transmitted sideband. The incoming frequencies are directed through the receiving directional filter to the demodulator, where modulation with the original carrier reproduces the voice frequencies together with other modulation products. The desired voice-frequency band is then separated from these products by the receiving low-pass filter.

In addition to performing the function of selecting desired and rejecting undesired currents, a filter, if operating in parallel with another as in the case of the directional filters or the line filters, should offer a high impedance to the transmitted currents of the other and thus prevent an excessive drain of these currents. Since these filters are designed for operation in parallel, either filter operated without the other would have somewhat different electrical characteristics.

The economies and reduction in size of these filters as compared to those of the type-*D* system are due to several factors. Improved paper condensers having the required stability are used. Compared to mica condensers, these condensers are less costly and smaller for a given capacity. Moreover, at a very slight increase in cost paper condensers are used which will withstand 1,000-volt line surges. Most of the condensers of the type-*D* system were designed for only 500-volt protection.

New types of coils with molybdenum permalloy cores having the necessary stability and low hysteresis losses are employed instead of the air-core solenoidal coils used in the type-*D* system. Since these new coils have less dissipation, the filters have flatter and wider transmission bands which contribute to improve telephone quality in the system. These coils are toroidal in shape and have very small stray fields and therefore small coupling with any nearby coils. This permits them to be packed closely together which results in a large decrease in the size of the filters. A further reduction in size and cost of the filters was effected by dispensing with individual containers for each coil. The elements of the filter are wired together and held in place in the filter can by a potting compound. This is poured around them, hermetically sealing the whole assembly.

The small size of the elements and the very low coupling

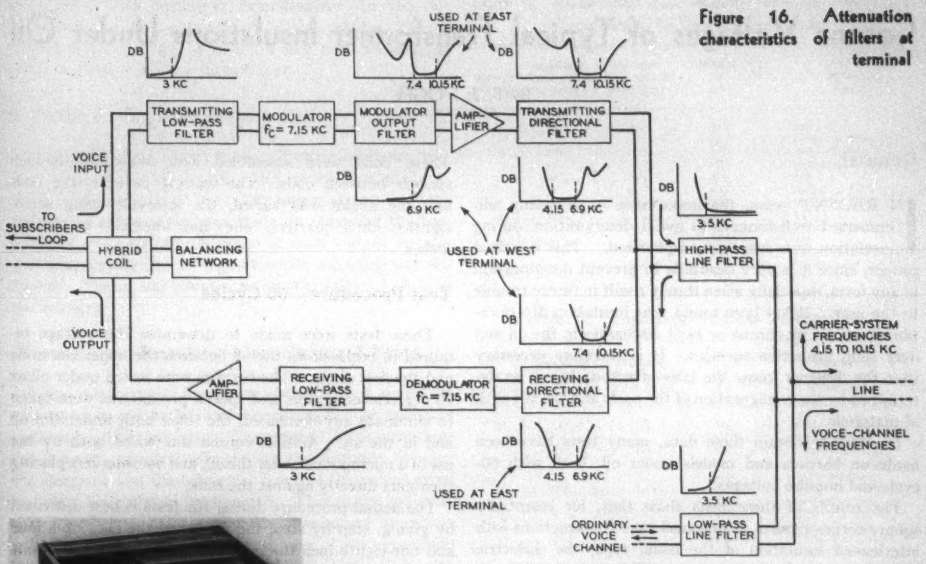

Figure 16. Attenuation characteristics of filters at terminal

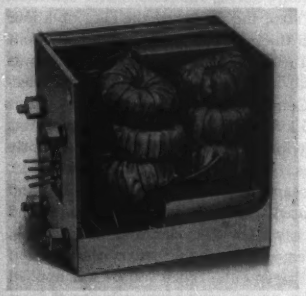

Figure 17. Filter (with cover cut away) showing general method of assembly

between them permit the assembly of more than one filter in the same can. For example, by a careful placing of the elements it was possible to place the transmitting and receiving low-pass filters and the modulator output filter in one can approximately three and one-fourth inches by four and one-fourth inches by four and one-fourth inches in size. A photograph of a high- and low-pass line filter with the can cut away is shown in figure 17. The filters for a terminal of this system require 70 square inches of mounting space or about one-fifth of that required for those of a type-*D* system.

Conclusions

The development of the type-*H* system is another step in extending the use of carrier systems. Improvements in performance and simplifications which are effective in reducing its cost as compared with the type-*D* system which it supersedes have been obtained. Reduction in size and provision for operation on a-c supply simplify its installation, particularly in outlying offices where suitable d-c power supply is not ordinarily available. Its portability makes it well suited to providing additional circuits required in cases of emergency. The type-*H* system is expected to have a large application in the Bell System telephone plant, and in addition to provide carrier circuits for the communication systems of other companies.

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Corona Voltages of Typical Transformer Insulations Under Oil

By F. J. VOGEL
ASSOCIATE AIEE

General

IN RECENT years, the importance of designing oil-immersed transformers to avoid deterioration during insulation tests has been emphasized. This is indeed proper, since it is very desirable to prevent deterioration in any form, especially when it may result in future trouble to the user. It has been found that insulation deterioration is caused by corona or local discharges in the oil and over solid insulation surfaces. It is therefore necessary that the designer know the laws of corona in oil, as determined by the configuration of the parts and the strength of materials.

In order to obtain these data, many tests have been made on barriers and models under oil, both with 60-cycle and impulse voltages.

The results of these tests show that, for essentially square-cornered parts, as in transformer constructions with interleaved insulation of the usual type, the dielectric strength varies approximately as the barrier thickness to the two-thirds power. These tests show that the ratio of impulse-voltage corona to 60-cycle corona is in the order of 2.2.[1,2] They also show that entrapped air within the insulation structure may greatly reduce the dielectric strength, and that the use of vacuum is very helpful in avoiding this difficulty.

In obtaining the data, two series of tests were made and a description of the test specimens, procedure and data follow.

Description of Barriers—First Series of Tests

The barriers tested were of three thicknesses, two and one-eighth inch, four and one-eighth inch, and seven inches. In order to simulate conditions in a transformer, an additional one-quarter-inch duct was placed between the barriers and the upper electrodes, making total separations of two and three-eighths, four and three-eighths, and seven and one-quarter inches. The barriers were all constructed with fullerboard sheets and ducts, similar to figure 1. Angles were interleaved as shown. The bottom electrode was a large plate. The top electrode consisted of five dummy coils of the same dimensions. The five coils were used in order to more closely simulate actual conditions in a transformer.

Each dummy coil was made of a three-eighths-inch-thick fullerboard sheet covered with lead foil, taped, and varnished, to a total thickness of about one-half inch. These coils were assembled with five-sixteenths-inch spacers between coils. The spacing between the coils and the angles was varied, the intervals being three-eighths, three-quarters, one and one-half, and three inches.

Test Procedure—60 Cycles

These tests were made to determine the voltage required to break down the oil between the upper electrode and the first angle. The barriers were tested under oil at 70 degrees centigrade, and special precautions were taken to eliminate any corona on the leads both under the oil and in the air. Audible corona was noted both by the use of a microphone under the oil, and by observers placing their ears directly against the tank.

The actual procedure during the tests is best described by giving, step by step, the results of the tests on a four and one-eighth-inch-thick barrier, with the dummy coils three inches from the first angle. After the barrier was immersed in the oil, it was shaken and the upper electrodes pounded. Considerable air was removed by this process. Then 125 kv was applied. Corona, which was present as shown by intermittent clicks, stopped abruptly after three minutes. When the voltage was removed, some air and gas escaped. Next 150 kv was applied and corona again appeared, gradually becoming weaker and at longer intervals, say 30 or 40 cycles, and disappearing. The voltage was removed, and the barrier shaken, and more bubbles were driven out. Then 180 kv was applied for five minutes, with no corona appearing during the last four minutes. At 200 kv, deterioration set in as indicated by a weak steady buzz. The voltage was immediately removed and then 150 kv, 180 kv, and 195 kv were applied without a sign of corona. Above 200 kv, corona appeared regularly, and thus 200 kv was determined as the corona voltage for this arrangement.

In every case, when bubbles were present, it was found that either the air had not all been removed, or that there

Table I. Test Results—60 Cycles—Oil Temperature Approximately 70 Degrees Centigrade

Barrier Number	Separation Dummy Coils to Plate	Distance Dummy Coils to Angle	Corona Point-Kv RMS	Maximum One-Minute Hold
1	2⅜	⅜	180	225
2	2⅜	¾	170	240
3	2⅜	1½	150	250
4	2⅜	3	130	
8	4⅜	⅜	290	360
9	4⅜	¾	280	
10	4⅜	1½	260	350
16	4⅜	3	200	
18	7¼	⅜	360	466

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1. For all numbered references, see list at end of paper.

was corona and insulation deterioration. In the determination of the corona point, it was required that a slightly lower voltage be held for five minutes without either bubbles or audible disturbance.

Procedure—Impulse Tests

Two series of tests were made, all using approximately $1^1/_2$x40 positive full waves. One series was made to failure, by applying at least 100 surges at each voltage setting. Another series was made by removing the barrier from the oil after 100 surges at each voltage setting, and determining the voltage at which marking was observed. The air was removed as far as possible by shaking the barriers.

Discussion of Results—First Series of Tests

These results are of importance because they show how entrapped air affects the insulation strength of an assembly under oil. They are also of importance in showing how the strength of oil is affected by the distance between the electrode and the barriers. Some of the values given by table I are shown on figure 2. This figure indicates that for a given arrangement the breakdown or corona voltage varies as the two-thirds power of the separation between the dummy coils and plate. The values also indicate that neither the 60-cycle nor impulse breakdown

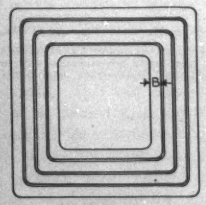
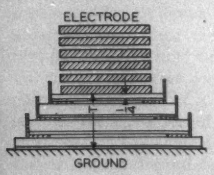


Figure 1. Sketch showing typical arrangement of barriers in the tests. B was three-eighths, three-quarters, one and one-half, and three inches. T was two and three-eighths, four and three-eighths, and seven and one-quarter inches



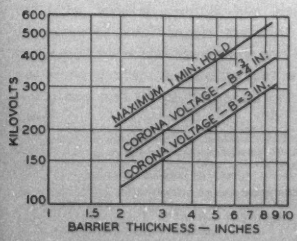


Figure 2. Relations between maximum one-minute hold or corona voltage and barrier thickness. Data taken under oil at approximately 70 degrees centigrade and with 60-cycle voltages

Table II. Breakdown Test Results—Impulse Tests—Oil Temperature 76 Degrees Centigrade

Barrier Number	Separation Dummy Coils to Plate	Distance Electrode to First Angle	Voltage in Kv	Number of Surges and Remarks
1	$4^1/_2$	$^3/_8$	870	100
			920	Failed on 59th Surge
2	$4^1/_2$	$^3/_8$	870	200—Slightly marked
			920	Failed on 187th Surge
3	$4^1/_2$	$^3/_8$	870	230
			920	Failed on 80th Surge
4	$4^1/_2$	$^3/_8$	870	Failed on 240th Surge
5	$4^1/_2$	$^3/_8$	820	446
			870	Failed on 161st Surge
6	$4^1/_2$	$^3/_8$	870	293
			920	Failed on 136th Surge

Table III. Endurance—Corona-Voltage Tests

Barrier Number	Separation Dummy Coils to Plate	Distance Electrode to First Angle	Voltage in Kv	Number of Surges and Remarks
12	$4^1/_2$	$^3/_8$	790	100—No marks
			830	100—Marked
7	$4^1/_2$	$^3/_8$	720	100—No marks
			790	110—No marks
			850	110—Marked
8	$4^1/_2$	$^3/_8$	790	100—No marks
			820	100—Marked
10	$4^1/_2$	3	590	100—No marks
			620	100—Marked
11	$4^1/_2$	3	590	100—No marks
			620	100—Marked

Table IV. Comparison of Corona Values—60 Cycle and Impulse

Separation Dummy Coils to Plate	Distance Electrode to First Angle (Inches)	Corona Voltage: 60 Cycle Crest-Kv	Corona Voltage: Impulse Kv $1^1/_2$ x 40 Pos. Wave	Ratio Impulse to 60 Cycles
$4^1/_2$	$^3/_8$	410	830	2.0
$4^1/_2$	$^3/_8$	396	835	2.1
$4^1/_2$	3	282	620	2.14

are much affected by the distance B between the coils and the first barrier for these particular tests, but this is not necessarily true in general, as shown by later tests. Table II also shows that insulation may stand hundreds of surges above the corona voltage as established by insulation marking. They also show that the impulse ratio for corona voltages is in the order of 2.1, but later tests on samples more closely similar to actual transformer construction, show a ratio of 2.2 or over.

Description of Barriers—Second Series of Tests

Since the preceding tests confirmed the necessity of removing all air, it was decided to make another series of tests, impregnating and filling the models with oil under vacuum. The insulation around the coil conductor has considerable bearing upon the dielectric strength, and so the new models were made with dummy coils of copper ribbon taped to 0.120 inch thickness with paper. The distance from the insulated coil to the first angle was

from three-eighths to three-quarters inch. The barrier thickness was two and five-eighths inches.

Test Procedure—60 Cycles and Impulse

In these tests, the voltage was raised in steps, holding the voltage for one minute at each step, until corona appeared as indicated by the formation of fine bubbles. A similar procedure was followed in obtaining impulse data, except that 100 positive wave impulses were applied at each voltage step. The impulse voltages were chopped by a gap at approximately three microseconds.

Table V. Results of Second Series of Tests

	60-Cycle Corona	Impulse Corona
	285	917
	281	920
Average—	283	918

The impulse ratio—impulse voltage at approximately 3 microseconds to 60 cycle crest voltage—is approximately 2.29. Corona at 60 cycles was not indicated until the breakdown voltage was reached.

Discussion of Results—Second Series of Tests

The results of these tests show how effectual the application of vacuum is in obtaining the full insulation strength of a transformer without the necessity or risk of carefully building the voltage up, and making so-called "bubble runs." They show clearly that large high-voltage transformers will have their maximum dielectric strength immediately when put in service, if filled with oil under vacuum. It also shows that the ratio of impulse to 60-cycle corona is of the same order as the impulse ratio of breakdown previously given, namely, 2.2 or more.

Conclusions

1. These tests, and previous experiences with models of transformers, show that corona can be avoided in transformers, both for 60 cycles and for impulses. It also shows that an average ratio between the impulse and 60-cycle crest voltage corona point of insulation similar to actual transformer insulation is 2.2.

2. These tests show the importance, both from a 60-cycle and impulse viewpoint, of the removal of all entrapped air. It is shown to be desirable to fill transformers with oil under vacuum, both for factory tests and at the time of installation. Tanks for many transformers of the larger sizes and higher voltages are made suitable for the application of vacuum.

3. These tests show that in some cases insulation will stand hundreds of impulses slightly above the corona point. This situation is similar to that found in 60-cycle tests, in which insulation withstands a higher value for one minute than the "marking" value.

Acknowledgment

The data covered in this paper were obtained over a period of years, and to those who helped in obtaining it, especially Mr. Carl Alsing and Mr. W. L. Teague, acknowledgment is due.

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Recent Advances in Resistance Welding

DURING the past few years fundamental concepts of resistance welding have not been greatly changed, progress being limited mostly to refinements in the art of welding procedure, design of machines and auxiliary equipment, and broader applications to industry in general. Advances may be classified under the headings of time, pressure, and current control which are fundamental to all resistance welders, materials to be welded including their preparation for welding, and means for placing the parts in the welding machine.

Perhaps the most noteworthy improvements have to do with the accuracy of the time period of current application. Controls whereby the primary current of the welding transformer is fed directly through either thyratron or ignitron tubes are coming into general use since they make practicable perfect timing of current application in exact periods of one-half cycle or larger multiples thereof. The maximum root mean square current capacity of these tubes has also been steadily increased up to 10,000 amperes at present for continuous welding operations. Not only have these exact tube controls been developed for use with much higher currents than were formerly used, but at the same time they have also made possible satisfactory commercial welding of materials which can only be welded in these short time intervals at high current densities. An auxiliary development to purely electronic timing is heat control which is accomplished by suitably delaying the ignition point of each tube for each half cycle of power current conducted and consequently cutting down the weld power for each half cycle. This has been used as a substitute, but usually as an auxiliary to the tap switch on the welding transformer for critical welding heat adjustments.

Probably stimulated by the performance of electronic control, very marked improvements in the operating speed of spot welding contactors has taken place. Also a large number of devices have been developed for more accurately controlling these contactors. Sending a current pulse of very brief duration or a series of impulses to the contactor magnet coil as determined by the rate of charge or discharge of a condenser, the inductance of a coil, or the operation of sensitive relays controlled by clock motors has allowed more satisfactory operation of magnetic contactors while refinements in the operation of mechanical contactors as synchronously co-ordinated with the welding circuits has also been considerable. Air-operated weld timers are also proving quite satisfactory on some classes of work and multiple control units are being used on automatic spot welders for controlling contactors and the motion of air operated heads and their dwell.

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Personnel of the subcommittee on resistance welding of the AIEE committee on electric welding: C. L. Pfeiffer, *chairman;* Malcolm Thomson, Carroll Stansbury, C. E. Heitman, J. W. Dawson, F. E. Taylor, H. A. Woofter, R. L. Browne, H. E. Stoddard, and Herman Lemp.

Welding machines have undergone marked improvement in the last few years, and this improvement is undoubtedly partly due to the more precise control now available. Pressure means on press welders such as air-cushion chambers in combination with cam action and the elimination of pounding are decided steps forward. The use of initial and final pressures on projection welding is also quite common. Better synchronization of machine operation and control makes possible fully automatic spot and projection welders with semiautomatic feed and discharge of parts to and from the welding position. Flash welders afford much better flash protection and the jaw movements whether co-ordinated by cam, spring, air, or hydraulic action or combination thereof have been much improved. Much higher capacities of transformer are being used and kilovolt-ampere capacities considerably over 1,000 are not at all unusual. Means for adjusting the welding current in smaller steps are more often provided especially for nonferrous materials. Some machines are also equipped with milling cutters which machine the work piece at their contact points prior to welding which reduces the possibility of variable power input into the weld area in successive welding operations. The use of automatically operated resistance welders for accurate annealing temperatures as controlled by photoelectric cells focused on individual parts has reached a high degree of development.

Multitransformer and multielectrode machines have come into extensive use during the last three years. Multielectrode machines such as the hydromatic spot welder using either one or more transformers has made possible very rapid spot welding on large assemblies and in addition has made possible individual quality control for each weld. Multitransformer machines are used to insure quality in individual weld spots and also to insure the proper current distribution on projection welding platens or large flash welding machines.

In order to speed up spot welding operations on strip materials wheel type electrodes are used under conditions similar to seam welding, but with longer periods of current interruption and consequent speeds as high as 120 feet per minute.

Special machines such as portable spot welders used for large assemblies of sheet iron parts and light frameworks are more popular than ever and are finding many more applications outside of the automobile industry where they were first put to use. In order to reduce the weight of the gun and lessen operator fatigue on large portable welders these are being built of aluminum or magnesium alloys in the hydromatic type so that the pressure cylinder is only about one inch in diameter instead of four or five. Plier type welders which are really miniature portable spot welders are also used for making electrical connections on meters, radios, or similar apparatus. Even percussion welders of which there are relatively few are increasing in number and the discharge of a bank of con-

densers or its equivalent into the primary of a resistance welding transformer finds applications on very critical welding setups.

Interrupted spot welding sometimes known as "persistence" welding is a relatively new method of welding very heavy sheets up to one inch in thickness. A series of welding current impulses is sent through the electrodes of a conventional spot welding setup giving the weld area time to heat up at the point of fusion but allowing the surface in contact with the electrodes to remain relatively cool. Such a set-up operates most consistently and with the best results by using electronically and automatically controlled timing periods, water-cooled electrodes and materials which spot weld readily such as low-carbon steel.

Practically all users of resistance welding machines now use either die-type electrodes or electrode tips made of special electrode materials. The use of these materials in die-type electrodes in combination with satisfactory cooling media makes possible the extension of resistance welding to a wide variety of special shapes including many not of sheet form. In addition to the tungsten-copper combinations and the cadmium copper alloy there are now a number of other electrode alloys available such as silver-tungsten and those which consist principally of copper, but contain small percentages of chromium, molybdenum, cobalt, beryllium, silicon, or zirconium.

The industries in which the application of resistance welding has made considerable strides and are using more welding equipment are radio, aircraft, electric machinery and equipment, refrigeration, metal sash and window frame, automobile, metal wares, telephone, farm machinery, railroad equipment, and metal furniture.

In the past, frequent criticism has been heard because many users of and even some manufacturers of resistance welding apparatus have operated on a decidedly rule-of-thumb basis. Attempts are being made to put resistance welding on something approaching a quantitative, scientific basis and some progress has been made by the introduction of various simple meters and measuring devices, especially adapted to the peculiar requirements, such as means for measuring the time of current application, electrode pressure meters, and instantaneous type current meters employing a gaseous glow lamp as the measuring element. Some tables have also been published showing the proper electrode area, time, current, and pressure to use on specific material of given dimensions. It is also felt that more effort should be expended on standardization of transformer and secondary circuit performance of welding machines and that more coordination along these lines between manufacturers of this equipment is desirable.

Temperature Limits for Short-Time Overloads for Oil-Insulated Neutral Grounding Reactors and Transformers

By V. M. MONTSINGER
FELLOW AIEE

THE PROTECTIVE DEVICE committee is working on the problem of preparing standards for neutral grounding devices. One of the most important points up for consideration is the selection of the temperature limits for various times of operations of the devices.

At the present time grounding transformers are designed to withstand a one-minute short circuit (duration of fault) without exceeding a temperature of 160 degrees centigrade.

The increasing use of oil-immersed neutral grounding devices—reactors, transformers, and Petersen coils—where the fault may last several minutes makes it necessary to standardize safe temperature limits for the longer periods of time.

In the case of grounding transformers the 160-degree-centigrade temperature limit is based on all heat being stored in the copper (neglecting the insulation) during the one-minute period. Obviously, where the time of fault lasts several minutes the maximum temperature reached will be influenced considerably by some loss of heat during the heating up period, especially if the winding has oil ducts between all coils. In other words, both heat storage and dissipation should be taken into consideration.

On the other hand, since many neutral grounding devices carry no load except during the fault, windings with no oil ducts between coils can and are sometimes used. In this case very little loss of heat will take place in the interior of the coil stack during the heating up period and the maximum temperature can be based on all heat being stored in the copper and its insulation. Again in this case the rate of cooling after the fault is removed is very much less than it is for coils with oil ducts. In fact, as shown later the cooling period of coils with no oil ducts is the controlling factor so far as aging of the insulation is concerned. Coils with oil ducts will be termed "open type" coils and coils with no oil ducts will be termed "closed type" coils.

It is the purpose of this paper to calculate the temperatures for various lengths of faults—up to 30 minutes—that will produce the same aging of insulation as is produced by 160 degrees centigrade for a period of one-minute fault—the present standard for grounding transformers.

I. Aging of Insulation

It is obvious that short-time temperature limits should be based upon the aging of the insulation. By aging is meant the mechanical deterioration (tensile strength) since electrical deterioration does not take place[1] until the material has become quite brittle and well carbonized.

To estimate the relative aging of insulations under short-time overload conditions, three steps must be taken, namely:

1. Calculation of the temperature rise of the winding until the load is removed.
2. Calculation of the cooling of the windings after the load is removed.
3. Integration of the area represented by the heating curve, taking into account both temperature and time.

Two types of coils are considered. First, coils of open type construction. Second, coils of closed type construction.

II. Heating Curve of Open Type Coils

Figure 1 shows a typical heating curve until conditions become constant of an oil-immersed transformer winding. This curve was based on the average of three curves having final copper rises in excess of the oil of 27, 42.5, and 86 degrees centigrade given on figure 5 of a previous AIEE paper.[2]

III. Cooling Curves of Open Type Coils

The cooling of windings of the open type construction has been calculated by an empirical formula shown later since, as was pointed out, in the AIEE paper,[3] the standard cooling curve equation $\theta_t = \theta_0\, e^{-Bt}$ does not apply to the usual open type oil-immersed winding. The cooling curves in terms of watts per pound, figure 2, were based on the formula (equation 8, reference 3):

$$\theta = 1.95\, W_c^{0.7}\,(1 - e^{-Lt}) \qquad (1)$$

where

θ = cooling in degrees centigrade
W_c = watts per pound of bare copper
= $2.16 \times 10^{-4}\, D^2$ (at 25 degrees centigrade) where D = amperes/square inch
e = 2.718
L = $0.106\, W_c^{0.3}$
t = time in minutes

To use the cooling curves shown in figure 2 under transient heating conditions (i. e., before the rise becomes constant) the temperature rise at the instant load is removed must be obtained in terms of watts per pound of bare copper for constant conditions. In other words, the watts per pound that would give the temperature rise (at the instant load is removed) for constant conditions must be found. Such a curve is shown in figure 3 for a typical

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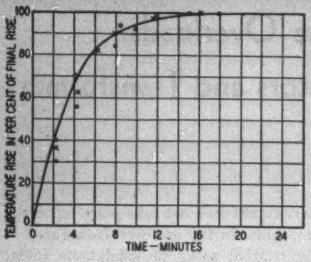
1. For all numbered references, see list at end of paper.



Based on three curves (27 degrees, 42.5 degrees, and 86 degrees copper over oil- final rises) figure 5 of reference 2

Based on curve with:
- • 27-degree final rise
- x 42.5-degree final rise
- o 86-degree final rise

Figure 1. Temperature rise of horizontal disk coils. Copper rise over oil until conditions become constant

coil stack.* For example, if, when the load or fault is removed, the temperature rise (over oil) is 55 degrees, 100 watts per pound (W_c) should be used in calculating the cooling by equation 1.

IV. Relative Aging of Insulation for Various Overloads

Several years' experience with grounding transformers has indicated that 160 degrees centigrade for one minute is satisfactory. As a working base it is therefore assumed that 160 degrees centigrade is safe for a one-minute load. It has been shown[1] that the rate of aging doubles for each 8 degrees centigrade increase in temperature or conversely is halved for each 8-degree decrease in temperature, and that the general form of the equation for expressing aging (or relative aging) as a function of both time and temperature can be written:

$$A = t_0 e^{0.088 T_2} \qquad (2)$$

where

A = units of aging
t_0 = time in minutes
e = 2.718
T_2 = temperature in degrees centigrade

In its present form equation 2 gives only relative aging units of insulation resulting from a continuous temperature T_2 applied for a length of time to, and represented by the rectangular area of the time-temperature graph. Later an empirical constant is added for the purpose of giving some idea of how long the insulation will last in service.

The equation for integrating temperature areas in the form of triangles and trapezoids is of the form

$$A = t_0 \left[\frac{e^{0.088 T_2} - e^{0.088 T_1}}{0.088 (T_2 - T_1)} \right] \qquad (3)$$

where T_2 and T_1 are the maximum and initial temperatures respectively of a triangle, but for a trapezoid T_2 and T_1 represent the vertical parallel sides—t_0 being the base of both triangles and trapezoids. See figure 7. See appendix for derivation of equation 3 and examples worked out.

Figure 4 shows the temperature limits for various durations of overloads on open type coils starting at 25 degrees that give approximately the same degree of aging obtained where the temperature reaches 160 degrees centigrade at the end of one minute. Figures 5 and 6 show similar curves except that the starting temperature is 75 degrees centigrade.

The methods used in integrating the temperature curve areas are illustrated in the appendix.

The results of these calculations are shown in table I.

Table I. Relative Aging of Open Type Coils

Time of Overload (Minutes)	Initial Temp. 25 Deg. Maximum Temp. (Deg. Cent.)	Initial Temp. 25 Deg. Units of Aging	Initial Temp. 75 Deg. Maximum Temp. (Deg. Cent.)	Initial Temp. 75 Deg. Units of Aging
1	160	380,000	160	778,000
5	149	405,000	149	770,000
10	139	410,000	138	799,000
30	112	400,400	119	787,400

It will be seen from table I that the amount of aging where the starting temperature is 75 degrees is approximately double that where the starting temperature is 25 degrees centigrade. The reason for this may be explained as follows: with a lower initial (oil) temperature, a greater overload is required to reach a given temperature limit than is required with a higher initial (oil) temperature. The higher the overload (or losses), the steeper the heating-up curve will be. Also, the higher the rise (over oil) at the time overload is removed, the faster in degrees per minute will be the cooling. (It is assumed that the oil temperature does not materially change during the entire period of heating and cooling.)

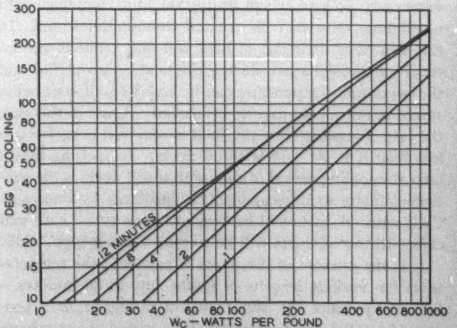


Figure 2. Cooling after shutdown of coils (with oil ducts)

Calculated by equation 1

* This curve was determined by tests on typical coils. The equation of the curve is

$\theta = 1.38\ W_c^{0.8}$

where θ is the temperature rise over average oil temperature and W_c is the watts per pound of bare copper. In all cases where temperature rise is mentioned, it means the copper rise in excess of the oil temperature.

The result is that with the steeper heating curves and faster cooling curves (with the lower initial temperature and greater overloads) the areas near the top of the heating and cooling curves are smaller than they are with the higher initial temperature and lower overloads. This difference in the areas can clearly be seen in the curves shown in figures 4 and 5. Since most of the aging occurs near the peak temperatures the size of the top areas is very important and hence the aging is less for the lower initial temperature. This means that to obtain the same aging during the overload period, for 25-degree initial temperature, approximately 8-degrees higher temperature could be allowed than for 75-degree initial temperature, since, it has been assumed that aging doubles for each 8-degree increase in temperature. In fact, the difference would be more than 8 degree because this does not take into account the aging during the time when no overloads are on, during which time it would, of course, be greater for a continuous temperature of 75 degrees than for a continuous temperature of 25 degrees centigrade.

Based upon the assumption that 160 degrees centigrade is safe for one minute and upon the values shown in table I, it would seem that the following temperature limits (or some of these limits) could be standardized for oil-immersed grounding neutral devices of open coil construction.

Table II. Temperature Limits for Open Type Coils

Overload Time (Minutes)	Degrees Centigrade
1	160.0
2	157.5
3	155.0
5	150.0
10	140.0
20	125.0
30	120.0

For closed type coil (with no oil ducts) the temperature limits, for a given initial temperature, are obviously lower than for open type coils for the reason that the cooling period is much longer than for open type coils. Based on the rate of aging being halved for each 8-degree decrease in temperature, to keep the aging on a coil stack with no oil ducts to the same value as for an open type coil reaching 160 degrees in one minute, the temperature should not exceed approximately 135 degrees centigrade. On the other hand, there is very little difference in aging whether the heating up period is one minute, five minutes or ten minutes, since most of the aging takes place after the load is removed.

Since most, if not all, neutral grounding devices of the Petersen coil type operate only when there is a fault and where the starting temperature would be at room temperature, it would seem that devices with closed type coils could operate during a fault at somewhat higher temperatures than could devices with open type coils, which permit of carrying some load continuously if occasion demands it. In other words, it may be safe to use the temperature limits given in table III for coils of the closed type. This is a question that should be given consideration when selecting temperature limits for standardization purposes.

Heating and Cooling of Closed Type Coils (No Oil Ducts)

In calculating the time-temperature curves of the closed type coils the heating-up curves were taken as approximately straight lines (except for the slight increase in resistance with increasing temperatures) since there is very little, if any, dissipation of heat from the interior of the coil stack during the short periods of time under consideration. Also, both the temperature rises and cooling curves were based on the thermal capacity of both the copper and intervening insulations. The thermal capacity of oil-immersed fibrous insulations is, by volume, approximately one-half that of copper.[3]

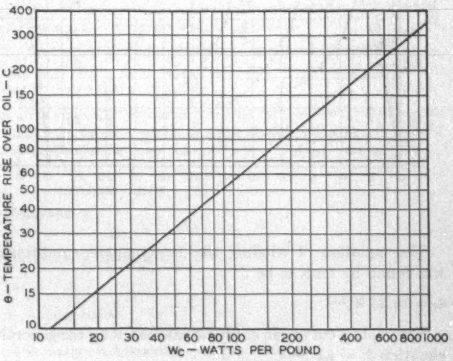


Figure 3. Temperature rise versus watts per pound of coil stack with oil ducts

Equation $\theta = 1.38\ W_c^{0.9}$

The cooling after load is removed was calculated by the standard cooling curve equation given in the first part of this paper. The size of conductor used in a closed type coil stack* on which tests were made to determine the curve of watts per pound versus temperature rise (for constant conditions) was 0.400 by 0.040 inch having 0.021-inch two sides thickness of insulation.

From the above

$$\beta = \frac{W_c 0.676\ \frac{a}{A+a}}{\theta_0}$$

$$= \frac{0.259\ W_c}{\theta_0}$$

where a = 0.400 by 0.040 inch
and A = 0.421 by 0.061 inch

* Consisting of 19 coils with no oil ducts.

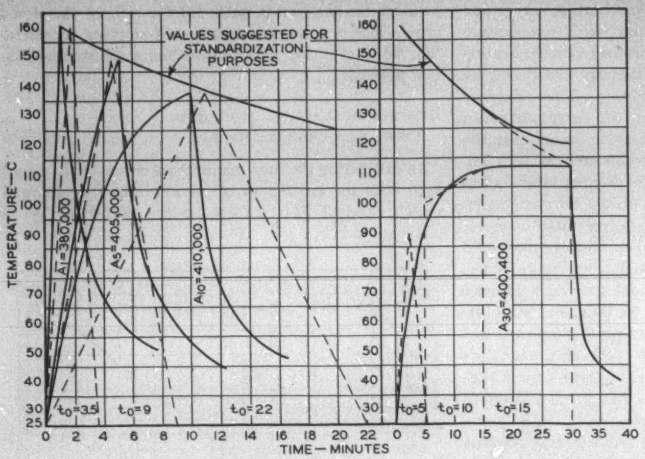


Figure 4. Various durations of loads and temperatures of oil-immersed windings (with coil ducts) to give approximately the same degree of aging of the insulation

Initial temperature T_1 = 25 degrees centigrade

Formulas shown in figures 5 and 6

The equation of winding rise for constant conditions was found by tests to be

$$\theta_0 = 18.25\ W_e^{0.44}$$

The cooling curve can easily be calculated by the general equation $\theta_t = \theta_0 e^{-\beta t}$.

The aging for a load attaining 160 degrees centigrade in one minute with a 25-degree initial temperature is approximately 3,290,000 units.

For a load attaining 152 degrees centigrade in 20 minutes the aging is approximately 3,000,000 units.

If it is assumed that 160 degrees is safe for one minute for closed type coils, calculations (for 25-degree initial temperatures) indicate that the following temperature limits could be permitted for 5, 10, 20, and 30 minutes.

Table III. Temperature Limits for Closed Type Coils

Overload Time (Minutes)	Degrees Centigrade
1	160
5	158
10	155
20	150
30	145

Since the aging in the above cases is in the order of 3,000,000 units, it is roughly 7.5 times that of an open type coil stack with 25-degree initial temperature.

It should be understood that the temperature limits obtained by the methods used in this paper are at best only approximations. Different designs will have different shapes of heating and cooling curves, although it is believed that the kind of coils chosen for these calculations are fairly well representative of the type of coils used. However, these calculated values should be more dependable than values arbitrarily chosen without any supporting data.

V. Life Expectancy

The life of any neutral grounding device obviously depends not only on the temperature limits chosen but also

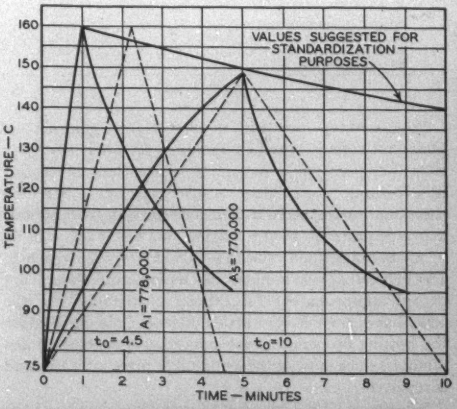


Figure 5. Various durations of loads and temperatures of oil-immersed windings (with coil ducts) to give approximately the same degree of aging of the insulation

Initial temperature T_1 = 75 degrees centigrade

T_2 = 160 and 149 degrees centigrade

$$A = t_0 \left[\frac{e^{0.088 T_2}\, e^{0.088 T_1}}{0.088\,(T_2 - T_1)} \right]$$

on the frequency of operation, which, of course, is unpredictable for this kind of service.

The following formula has been given[1] for estimating the life of insulation when operating continuously at various temperatures:

$$Y = 7.15 \times 10^4 e^{-0.88x} \quad (4)$$

where

Y = life in years
x = temperature degrees centigrade
e = 2.718

Equation 4 gives the following years of life for 90, 95, 100, and 105 degrees centigrade temperatures:

Table IV

Temperature (Deg. C.)	Years—Life (Approximate)
90	26
95	17
100	11
105	7

If we choose 26 years as a reasonable life, this means that the equivalent of 90 degree continuous temperature should not be exceeded.

By equation 2 the units of aging for 26 years at 90 degrees is

$$A = (26 \times 365 \times 24 \times 60)\, e^{0.088 \times 90}$$

$$= 37{,}600{,}000{,}000 \text{ units}$$

With an initial temperature of 25 degrees the number of permissible operations per day would be (approximately):

$$\frac{37{,}600{,}000{,}000}{26 \times 365 \times 395{,}000} = 10 \text{ times for open type coils,}$$

or,

$$\frac{37{,}600{,}000{,}000}{26 \times 365 \times 3{,}000{,}000} = 1.3 \text{ times for closed type coils.}$$

These numbers of operations appear to be more than would ever occur under service conditions.

Conclusions

As a result of the study given in the paper the following conclusions have been drawn:

1. These data should make it possible to establish fairly dependable temperature limits for short-time overloads for oil-immersed neutral grounding devices.

2. For neutral grounding devices having open type coil construction, where the time exceeds one minute, most of the aging of insulation takes place during the heating-up period.

3. For neutral grounding devices having closed type coil construction, most of the aging takes place after the overload is removed; that is, during the cooling period.

4. For neutral grounding devices that carry no load, except during a fault, the temperature limits given in table III should be safe for standardization purposes.

Appendix

Derivation of equation 3:

Let

A = aging units
T = temperature, degrees centigrade
T_2 = maximum temperature degrees centigrade
T_1 = some lower temperature—see figure 7
t_0 = time in minutes

When the aging doubles for each 8-degree increase in temperature, the exponential constant is 0.088. Therefore:

$$A = \int_0^{t_0} e^{0.088T} dt$$

$$T = T_1 + (T_2 - T_1)\frac{t}{t_0}$$

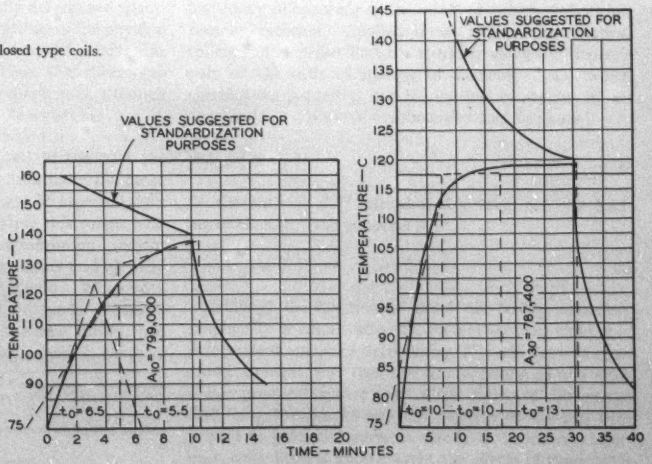


Figure 6. Various durations of loads and temperature of oil-immersed windings (with coil ducts) to give approximately the same degree of aging of the insulation

Initial temperature T_1 = 75 degrees centigrade

$A = t_0 e^{0.088 T_2}$ (for rectangles)

Formula shown in figure 5 used for triangles (T_1 = 75 degrees)

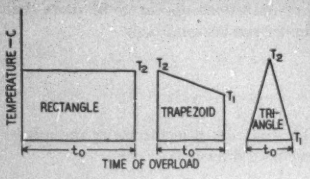


Figure 7. Temperature areas applicable to integration by:

Equation 2 for rectangles

Equation 3 for trapezoids and triangles

$$A = \int_0^{t_0} e^{0.088\left[T_1+(T_2-T_1)\frac{t}{t_0}\right]}\,dt$$

$$= e^{0.088T_1}\int_0^{t_0} e^{0.088(T_2-T_1)\frac{t}{t_0}}\,dt$$

$$= \frac{e^{0.088T_1}t_0}{0.088\,(T_2-T_1)}\left[e^{0.088(T_2-T_1)}-1\right]$$

$$= t_0\left[\frac{e^{0.088T_2}-e^{0.088T_1}}{0.088\,(T_2-T_1)}\right] \qquad (3)$$

Examples

1. Five Minute Load

For illustrative purposes the aging for the five-minute load, shown in figure 4, will be worked out in detail.

The temperature rise (found by trial) is 149 − 25 = 124 degrees centigrade. By figure 1 the rise in five minutes is 75 per cent of constant and at, say, three-minutes is 55 per cent of constant. Then the rise at three minute period (of the five-minute load) should be $\frac{55}{75}$ = 73.3 per cent of 124 degrees or 91 degrees centigrade. 91 + 25 = 116 degrees actual temperature. The other points on the curve are worked out similarly.

As the cooling is a function of the watts per pound of copper at the instant load is removed, it is necessary to convert the rise in terms of watts per pound. A rise of 124 degrees represents a loss of 275 watts per pound by figure 3.

By figure 2 the cooling in one minute is 45 degrees. 149 − 45 = 104 degrees temperature at the six-minute point. The cooling for two minutes is 70 degrees and 149 − 70 = 79 degrees centigrade temperature at the seven-minute point.

The next step is to resolve the temperature curve into a triangle of approximately the same area, especially the top portion where the aging is most severe.

The triangle shown by dashes has a base of nine minutes and a peak temperature of 149 degrees centigrade.

By substituting in equation 3 and letting $T_2 = 149$, $T_1 = 25$, and $t_0 = 9$,

$$A = 9\left[\frac{e^{0.088\times 149} - e^{0.088\times 25}}{0.088\,(149-25)}\right]$$

$$= 9\left(\frac{490{,}000}{10.9}\right) = 405{,}000 \text{ units.}$$

2. Thirty-Minute Load.

The aging for the 30-minute load shown in figure 4 is as follows

$$A_{12} = 15e^{0.088\times 112} = 282{,}000$$

$$A_{10} = 10\left[\frac{e^{0.088\times 112} - e^{0.088\times 100}}{0.088\,(112-100)}\right] = 116{,}000$$

$$A_5 = 5\left[\frac{e^{0.088\times 90} - e^{0.088\times 25}}{0.088\,(90-25)}\right] = 2{,}400$$

400,400 total units.

References

1. Loading Transformers by Temperature, V. M. Montsinger. AIEE Transactions, volume 49, 1930, page 776.

2. Predetermination of Self-Cooled, Oil-Immersed Transformers Before Conditions Are Constant, W. H. Cooney. AIEE Transactions, volume 44, 1925, page 611.

3. Cooling of Oil-Immersed Transformer Windings After Shutdown, V. M. Montsinger. AIEE Proceedings, volume 36, part 1, 1917, page 711.

A New Correlation of Sphere-Gap Data

By D. W. VER PLANCK
ASSOCIATE AIEE

Synopsis: The similarity principle for electrical discharges is used to correlate the most recent AIEE sphere-gap data for both positive and negative impulses. Empirical formulas are developed from which the entire range of data can be calculated to within about 1.5 per cent. Some practical results of this study are:

1. Spark-over curves for each value of spacing to diameter ratio are straight lines when plotted to logarithmic scales, at least to within the certainty of the present data.

2. A spark-over voltage chart covering the entire useful range of sphere sizes, spacings, and air densities can be constructed easily.

3. New air-density correction factors are derived which differ appreciably from those previously published.

Introduction

THE SPHERE GAP, widely used for measuring high voltages, is not an absolute standard; that is, its performance cannot be calculated from fundamental considerations. The standard calibration is based on measurements mainly in terms of low-voltage standards through the use of potential transformers or potential dividers. The curves for the eight standard sphere sizes are commonly regarded as independent entities each relying for its accuracy on a separate testing program. Knowledge of an orderly relationship between the curves would fulfill a definite need. It is the purpose of this paper not only to show that there is indeed such a relation but that it is of surprisingly simple form. A direct calculation by classical electrostatic theory is not feasible because for air the puncture strength, or maximum gradient just prior to spark-over, different for each electrode configuration and spacing, is known only through the reverse calculation from experimentally determined spark-over curves. Nor is the present knowledge of the physical mechanism of sparking sufficiently exact to form the basis for accurate calculations. Thus the sphere-gap calibrations are the result of direct experiments, although empirical formulas have been of considerable use in smoothing the data and for extrapolation.

Of the empirical methods developed in the past the best known, due to Peek,[1] gives good results in the range for which it was intended, but, as might be expected, fails when used for extrapolation far outside this range. Its basis is an empirical formula for the maximum gradient prior to spark-over involving sphere radius and air density, but not spacing as it probably should. When both spheres are insulated the spark-over voltage is calculated from this gradient by classical electrostatic theory, and when one sphere is grounded, by an empirical method. The AIEE standard air-density correction factors were calculated from Peek's gradient formula.

Bellaschi and McAuley[2] have smoothed and extrapolated their data by making use of their discovery that for each constant ratio of sphere gap opening to sphere diameter plots of average gradient against the logarithm of sphere diameter are essentially straight lines for sphere diameters above 25 centimeters. Later Bellaschi[3] elaborated on this method giving empirical formulas with numerical values for their parameters.

The new method which is the subject of this paper, while empirical, appears to have a wider range of usefulness and greater simplicity than methods published heretofore. It is based on the principle of similarity for electrical discharges, a principle well established in the field of physics, but whose power seems not to have been fully appreciated by engineers in this country.

The Principle of Similarity for Electrical Discharges

The principle of similarity for electrical discharges, a generalized form of Paschen's Law, states that in a given gas "Geometrically similar systems will discharge at the same potential if the products of their leading dimension and mass of gas per cubic centimeter are the same; or the discharge potential is a function of the product of density and a dimension for similar systems."[4] This law originally deduced from, and since substantiated by direct experimental evidence, the extent of which is mentioned below, has also been shown by Townsend[5] to result from his theory of sparking as the result of cumulative ionization by collision. Applied to an isolated symmetrical sphere gap it means that the sparking voltage V depends only on the ratio of spacing to diameter (S/D), which specifies the geometry, and the product of spacing by air density $(S\delta)$. Written symbolically this becomes

$$V = F\left(S\delta, \frac{S}{D}\right) \tag{1}$$

Or alternatively if D instead of S is taken as "the leading dimension," the equation is

$$V = \Phi\left(D\delta, \frac{S}{D}\right) \tag{2}$$

Although the functions F and Φ can be expressed only graphically or empirically, it is evident that the number of independent variables determining V is not three as commonly thought, but two, the combinations $S\delta$ and S/D.

For practical sphere gaps other ratios of dimensions describing the shanks and the position of the gap with respect to grounded surfaces should be included. However, since little is known about the effects of these other

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1. For all numbered references, see list at end of paper.

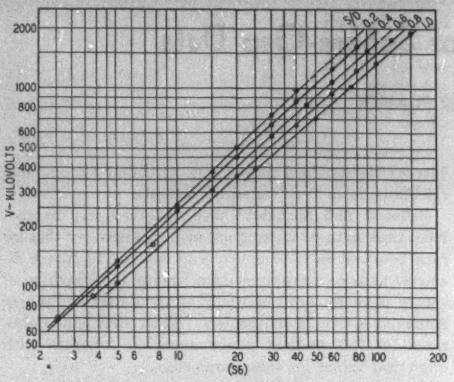


Figure 1. Lines for which S/D is constant

Data from AIEE Revised Standards for Negative Impulse

geometric ratios, except that in practice they are usually small, they are ignored here. Necessarily F and Φ depend on whether both spheres are insulated or one is grounded and if so on polarity as well. Except for density, whose primary significance in this connection is that it is inversely proportional to the mean free path, other properties of the air, such as its humidity, have no appreciable effect on V within the range of S/D used in measurement practice.

Researches on the similarity principle for spheres are well summarized by Whitehead,[4] Thomson,[6] and Bowker.[7] V has been shown to depend only on the product $(S\delta)$, with S/D constant, independently of S, temperature and pressure. With hydrogen and nitrogen the temperature was carried to over 800 degrees centigrade at pressures from 0.25 to 2 atmospheres. In air the law holds up to at least 300 degrees centigrade, and at room temperature from pressures of a few millimeters to about 10 atmospheres, above which there is a departure. The spheres used were small, from 1 to 2.5 centimeters in diameter, and S/D was usually less than 0.2 although in some cases as high as 0.5. Taking $\delta = 1$ for normal atmospheric conditions of 760 millimeters and 25 degrees centigrade, the maximum $(S\delta)$ attained was about 2.0 for which approximately $V = 60$ kv.

Correlation of the Data

As a consequence of the usual testing procedure, sphere-gap data are customarily presented as separate curves or tables of V vs. S, $(\delta = 1)$, for each size of sphere. Variations in δ are taken into account by means of tabulated correction factors. Three independent variables S, D, and δ are thus considered in determining V. However, as shown here by the similarity principle, V is really a function of only two independent variables, the combinations $(S\delta)$ and S/D. A function of two variables is not hard to tabulate, but it is even easier to show graphically on a chart. A number of forms of chart were tried in an effort to find one that would be not too large and still include the desired range of variables, easy to read accurately, and easy to construct.

In the course of this study it was discovered that, to within the certainty of the best data available, curves of V vs. $(S\delta)$ for constant S/D plotted to logarithmic scales are *straight lines* over the entire useful range of sphere gap

Table I. Parameters for Equation 3

One sphere grounded: $2 < (S\delta) < 200$; $5 < (D\delta) < 200$

	For Negative Impulse and 60 cycles		For Positive Impulse	
S/D	K	α	K	α
0.1	30.10	0.941	30.15	0.941
0.2	29.95	0.940	30.15	0.940
0.3	29.65	0.931	30.15	0.931
0.4	29.25	0.917	30.15	0.917
0.5	28.55	0.904	30.15	0.900
0.6	27.45	0.895	30.10	0.884
0.7	26.21	0.891	29.70	0.872
0.8	24.96	0.888	29.00	0.865
0.9	23.69	0.886	28.00	0.860
1.0	22.44	0.885	27.00	0.855

Table II. Comparison of Calculated and Standard Spark-Over Voltages, Negative Impulse and 60 Cycles

Upper figures are calculated; lower figures are from AIEE Standards*

S/D	D = 6.25	12.5	25	50	75	100	150	200
0.1			71.3	136.9	201	263	385	504
			72	136	200	261	383	506
0.2		70.9	136.0	261	382	501	733	960
		70.8	136	260	380	504	736	973
0.3	53.2	101.5	193.5	369	538	703	1,026	1,341
	53.8	100.6	192	367	528	700	1,040	1,346
0.4	67.8	128.0	242	456	662	861	1,249	1,626
	68.8	127.0	241	451	653	862	1,254	1,635
0.5	80.0	149.7	280	524	756	981	1,415	1,835
	81.0	147.5	278	519	751	985	1,410	1,857
0.6	89.6	166.6	310	576	828	1,072	1,540	1,992
	90.3	164.5	309	573	827	1,084	1,552	2,027*
0.7	97.6	181.1	336	623	894	1,155	1,657	2,141
	98.2	179.5	338	615	890	1,163	1,662	2,169*
0.8	104.2		357	661	947	1,222	1,752	2,263
	105.5		362	651	945	1,234	1,760	2,293*
0.9			374	691	989	1,276	1,828	2,350
			379	681	992	1,295	1,820	2,395*
1.0			387	716	1,024	1,321	1,892	2,440
			393	707	1,025	1,338	1,900	2,475*

* Extrapolated by AIEE, not used in determining parameters.

Figure 2. Parameters in the formula $V = K(S\delta)^{\alpha}$

One sphere grounded, both impulse polarities

$2 < (S\delta) < 200$

$5 < (D\delta) < 200$

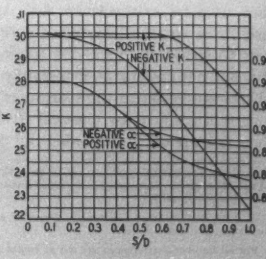


Table III. Comparison of Calculated and Standard Spark-Over Voltages, Positive Impulse

Upper figures are calculated; lower figures are from proposed AIEE standards[9]

S/D	D							
	6.25	12.5	25	50	75	100	150	200
0.3	54.1	103.2	196.8	375	547	715	1,043	1,364
	54.3	101.7	196	374	548	715	1,055	1,364
0.4	69.9	131.9	249	470	682	888	1,288	1,677
	69.3	132.3	252	474	687	888	1,293	1,671
0.5	84.1	156.9	293	546	787	1,020	1,468	1,902
	81.8†	158.0	296	547	786	1,024	1,453	1,896
0.6			330	609	871	1,123	1,607	2,073
			334	605	870	1,124	1,597	2,069*
0.7			360	660	939	1,207	1,719	2,209
			364	655	939	1,209	1,718	2,220*
0.8			387	705	1,001	1,284	1,823	2,339
			390	698	999	1,284	1,824	2,360*
0.9			407	740	1,048	1,342	1,902	2,437
			409	732	1,046	1,344	1,902	2,464*
1.0			423	766	1,083	1,385	1,958	2,505
			426	738†	1,081	1,390	1,944	2,543*

* Extrapolated by AIEE, not used in determining parameters.
† Not used in determining parameters.

testing. For examples, see figure 1. These curves are described by the empirical equation

$$V = K(S\delta)^{\alpha} \qquad (3)$$

Where K and α are parameters depending only on the ratio S/D and the polarity. The variation of these parameters with S/D is shown in table I and figure 2, for one sphere grounded and both impulse polarities.

The source of the data for 60-cycle and negative impulse voltages is the partial revision of AIEE Standards No. 4 published in July 1936,[8] and that for positive impulse voltages is a part of the same revision as yet unpublished.[9] The revision is based mainly on the extensive researches of Bellaschi and McAuley[2] and of Meador.[10] Points at desired values of S/D not appearing in the tables were obtained from plots. Using values of S/D for each tenth up to 1.0, K and α were adjusted to best fit the data subject to the condition that curves of K and α against S/D should be smooth. A large scale logarithmic plot was used to obtain preliminary values of K and α which were then refined by successive calculations using logarithms and a computing machine.

The data used and the corresponding calculated values are shown together in tables II and III for the range of

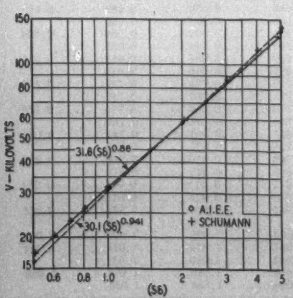
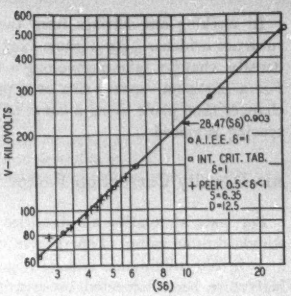


Figure 3. Comparison of formulas for use above and below (Sδ) = 2.0; S/D < 0.2

Figure 4. Agreement of Peek's low-density tests with AIEE Standard values for δ = 1 and with the new formula for S/D = 0.508



conditions defined by $(S\delta) > 2.0$; $6.25 < D < 200$; $S/D < 1.0$; and $\delta = 1.0$. As to accuracy, a comparison of the calculated values and the data for the 116 points given in the tables reveals that 83 agree to better than 1 per cent, 28 to between 1 and 1.5 per cent, and 3 to between 1.5 and 1.9 per cent. Two values for positive impulse are disregarded entirely because they are so far out of line as to be almost certainly in error.

When $(S\delta) < 2.0$ calculations using the parameters of table I no longer fit the data so closely, the departure at $(S\delta) = 1.0$, $S/D = 0.1$ being nearly 5 per cent. In this region the true curves to logarithmic scale depart appreciably from linearity although the curvature is still not great. In the range $0.4 < (S\delta) < 2.0$; $S/D < 0.2$, the formula

$$V = 31.6(S\delta)^{0.88} \qquad (4)$$

gives a good approximation to data collected by Schumann[11] for a uniform field, $S/D = 0$, and to the few AIEE data in this range. These data, equation 4, and the line for $(S\delta) < 2.0$ and $S/D = 0.1$ are plotted for comparison in figure 3.

The data discussed so far are for values of $(S\delta)$ when $\delta = 1$, that is for standard atmospheric conditions. Test data for $\delta \neq 1$ and $(S\delta) > 2.0$ are not easily found in the literature. Some reported by Peek[1] for 12.5-centimeter spheres, one grounded, spaced 6.35 centimeters ($S/D = 0.508$) at relative air densities down to about 0.5 are plotted in figure 4. There is close agreement between these points and the line defined by equation 3 with the parameters for $S/D = 0.508$ read from figure 2.

Sphere-Gap Spark-Over Chart

The sphere-gap function, F in equation 1, can be mapped to the best advantage on a chart whose co-ordinates are V and $(S\delta)$ to logarithmic scales. Curves of V against $(S\delta)$ for constant S/D, spaced at convenient intervals, are then, to the present certainty of the data, the perfectly straight lines whose parameters K and α have been given. Curves of constant $(D\delta)$ can be drawn through points easily located on the constant S/D lines. In addition to simplicity of construction the logarithmic scales give compactness together with constant accuracy for all parts of the chart. A chart for negative impulses and 60 cycles is shown to a small scale in figure 5.

In working out settings from the chart the following rules are evident. For a given fixed gap with varying air density, changes take place along a line of constant S/D. For a particular sphere size at a particular air density, changes take place along a curve of constant $(D\delta)$ as the spacing is varied.

Air-Density Correction Factor

For tests at relative air densities other than unity the standard table values of spark-over voltage, which are for $\delta = 1$, 760 millimeters and 25 degrees centigrade, have heretofore been corrected by means of the multiplying factors given in AIEE Standards No. 4. These factors, which are identical with those calculated by Peek[1] and those recommended by the I.E.C.[12] are tabulated for each size of sphere and for $0.50 < \delta < 1.10$. No account is taken of any effect due to changes in S/D, nor of polarity since they are for 60 cycles.

The method advocated here is based on the similarity law and contained in the chart, figure 5. For a given S/D the spark-over voltage for any δ is read from the curve of V vs. $(S\delta)$, which may have been found originally for some other δ. If a chart is not available, then with the aid of the empirical formula 3 the spark-over voltages of a particular sphere gap at two different densities are related by

$$V_2 = V_1 \left(\frac{\delta_2}{\delta_1}\right)^{\alpha} \qquad (5)$$

The air-density correction factor for use with the standard values is thus simply $(\delta)^{\alpha}$, and depends not on D but on S/D and the polarity. The new factors for each polarity and one sphere grounded are shown in table IV. That they should depend on the polarity of the unsymmetrical gap is not surprising when it is remembered that

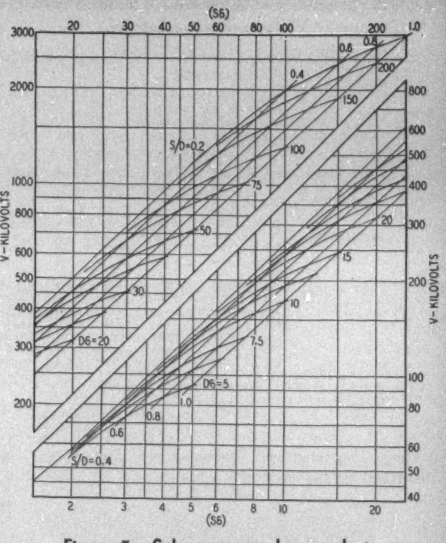


Figure 5. Sphere-gap spark-over chart

One sphere grounded, negative impulse and 60 cycles

positive and negative discharges have distinctly different properties. A comparison with the present standard factors shows for negative impulses or 60 cycles the possibility of a maximum difference between them of about 1 per cent at $\delta = 0.9$ increasing to about 5 per cent at $\delta = 0.5$. In general, the direction of the difference depends on both D and S/D. When $\delta < 1.0$ the new factors for

Table IV. Air-Density Correction Factors, One Sphere Grounded

Where they differ, factors for positive impulse are printed below

δ	$2.0 < (S\delta) < 200$									$0.4 < (S\delta) < 2.0$
	S/D 0.2 and less	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.2 and less
0.50	0.521	0.524	0.530	0.534	0.538	0.539	0.540	0.541	0.541	0.543
				0.536	0.541	0.546	0.550	0.551	0.553	
0.55	0.570	0.573	0.579	0.582	0.585	0.586	0.588	0.589	0.589	0.591
				0.584	0.589	0.593	0.596	0.598	0.600	
0.60	0.618	0.621	0.626	0.630	0.633	0.634	0.635	0.636	0.636	0.638
				0.631	0.636	0.640	0.643	0.644	0.646	
0.65	0.667	0.670	0.674	0.678	0.680	0.681	0.682	0.683	0.683	0.685
				0.679	0.683	0.687	0.689	0.690	0.692	
0.70	0.715	0.717	0.721	0.724	0.727	0.728	0.729	0.729	0.729	0.731
				0.725	0.729	0.732	0.734	0.736	0.737	
0.75	0.763	0.765	0.768	0.771	0.773	0.774	0.775	0.775	0.775	0.776
				0.772	0.775	0.778	0.780	0.781	0.782	
0.80	0.811	0.813	0.815	0.817	0.819	0.820	0.821	0.821	0.821	0.822
				0.818	0.821	0.823	0.824	0.825	0.826	
0.85	0.859	0.860	0.862	0.864	0.865	0.866	0.866	0.866	0.866	0.867
					0.866	0.868	0.869	0.870	0.870	
0.90	0.906	0.907	0.908	0.909	0.910	0.911	0.911	0.911	0.911	0.911
				0.910	0.911	0.912	0.913	0.913	0.914	
0.95	0.952	0.953	0.954	0.954	0.955	0.956	0.956	0.956	0.956	0.956
								0.957	0.957	
1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.05	1.047	1.046	1.046	1.045	1.045	1.044	1.044	1.044	1.044	1.044
					1.044	1.043	1.043	1.043	1.043	
1.10	1.094	1.093	1.091	1.090	1.089	1.089	1.088	1.088	1.088	1.088
					1.088	1.087	1.086	1.085	1.085	

6.25-centimeter spheres are smaller than the old over the whole range of spacing, while for 100-centimeter spheres they are always larger. The possible differences between the new positive impulse factors and those now in Standards No. 4 are even greater, about 1.3 per cent at $\delta = 0.9$.

Concluding Remarks

The method given here for calculating the standard sphere gap spark-over voltages has an accuracy of better than 1.5 per cent, which is well within the tolerances in this field of measurement. AIEE Standards No. 4 specifies an accuracy of 2 per cent for tests carried out in accordance with its instructions, while in the revised standards this figure has been increased to 3 per cent in recognition of the difficulty of attaining the ideal conditions in practice.

It is possible that in many cases the new air-density correction factors are enough different from those now in use to materially reduce the discrepancies between the results of the various standardizing laboratories.

It is suggested that future standardization tests be guided by the facts brought out here; that in accordance with the similarity principle the basic variables are S/D and $(S\delta)$; and that with S/D held constant the relation of V to $(S\delta)$ is a very simple one. Even though more precise tests may show the empirical formula 3 not quite exact, the curves of constant S/D to logarithmic scale must be so nearly linear that they can be firmly established using only four or five wisely chosen sphere sizes.

List of Symbols

V = Spark-over voltage in kilovolts crest.
D = Diameter of sphere in centimeters.
S = Spark-over distance between spheres in centimeters.
δ = Relative air density; unity for 760 millimeters and 25 degrees centigrade
K = Empirical coefficient depending on S/D.
α = Empirical exponent depending on S/D.
F, Φ = Functions of unknown mathematical form.

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Electrical Equipment for Modern Urban Surface Transit Vehicles

By S. B. COOPER

Synopsis: This paper reviews modern urban surface transit developments, traces the reasons for the changes, and outlines some of the problems involved and their solution.

THE CHANGING conditions that have produced such marked developments in public urban transportation vehicles during the past ten years have naturally brought about corresponding changes and developments in the electrical propulsion equipment.

During the period from 1926 on, the increasingly serious competition from the private automobile and the gas bus made it more and more evident that the transit industry could not continue to compete successfully with these newer forms of transportation while still using the tools and methods developed during the previous decade with little change up to that time other than detail improvements.

The need became increasingly apparent about this time for vehicles which would do several things:

1. Provide a faster, smoother ride.
2. Provide a more attractive vehicle from the standpoint of passenger appeal—finish, seats, lights, quietness, etc.
3. Reduce operating costs.

These requirements led to a greatly accelerated rate of development in cars, trolley coaches, and gas electric busses, and in the electrical equipment for each of these vehicles.

The first major efforts of this period in improvements in cars lay along the lines of:

1. Reduced weight.
2. Lower floors and steps.
3. Reduction in unsprung weight.
4. Reduction in noise.
5. Improved braking.
6. Increased acceleration.
7. Automatic acceleration.
8. Better appearance.

These objectives led to a period of intensive development from 1927 to 1930 during which were introduced *WN* double reduction, single reduction, and worm type gear units, which in turn called for and made possible the 300 volt, high-speed spring-supported motor now so generally accepted. New ideas were introduced along truck and body lines, largely to take advantage of features made possible by the new motor and drive developments. Also the need for more rapid acceleration brought about the introduction of the variable automatic controls of different types—it being generally felt that the higher rates and the general adoption of one man operation made automatic acceleration very desirable if not essential.

This period of intensive development, with aims sometimes paralleling and sometimes in conflict, together with a growing realization of the urgent need for some degree of standardization, no doubt had a part in the organization during 1930 of the Presidents' Conference Committee.

Other papers deal with the history and accomplishments of this committee; suffice it to say that the results obtained in the past two and a half years fully justify its activity.

Following the early period of investigation and research by the committee, the problem presented to the designers of electrical equipment was about as follows:

1. To produce a 55-horsepower motor lighter and smaller than anything so far achieved.
2. A control equipment which would permit automatic acceleration rates up to 4.75 miles per hour per second so smooth that even standing passengers would not be able to detect individual notches.
3. The motor and control equipment to be so designed as to take the major share of braking duty away from the shoe on the wheel, and to be capable of producing in conjunction with the air-actuated wheel brakes and the magnetic track brakes smooth braking rates up to 4.75 miles per hour per second in service applications and up to 8 or 9 miles per hour per second in emergency.

Standardized mounting and housing arrangements were called for, with means for recovery of accelerating and braking resistor losses for car heating when required.

Two different equipments are now available to produce these results. It is felt that detailed description of the apparatus and functioning is beyond the scope and purpose of this paper—these details are available to those interested. The electrical manufacturing companies have produced equipment fulfilling the objectives established by the committee. The 55-horsepower 300-volt motors weigh about 700 pounds each in contrast to 2,185 pounds for an axle-hung type motor of corresponding capacity. The motor barrel diameter is 15 3/4 inches and the length over the housings about 25 inches. Figure 1 shows a motor of this type; such motor designs have been made possible by the use of high-temperature insulation, improved antifriction bearings, and perhaps most of all by developments in armature and commutator design and construction which permit peripheral speeds way beyond anything considered possible ten years ago.

It happens that during the period from 1926 to 1930 there was also a rapid and intensive development in a-c motors for steam-railroad electrification, leading up to the Pennsylvania electrification program of 1931. Many of the improvements, processes, and principles worked out

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in connection with these a-c motors were found directly applicable to d-c motors as well. This contributed greatly to the development of the light-weight high-speed motors which we have today for cars, trolley coaches, and gas and oil electric busses.

For instance the technique of application of antifriction bearings to railway motors underwent tremendous development during this period. The recognition of the necessity for careful choice and maintenance of adequate internal clearances in these bearings under railway motor conditions might be cited. The growing use of cylindrical roller bearings is at least in part due to the ease and accuracy with which the internal clearance after assembly can be measured.

The extreme importance of keeping lubricant *in* and dirt *out* of these bearings has become more generally understood. The use of the steel labyrinth type of seal without rubbing or wearing surfaces has aided greatly in the accomplishment of these objectives without the necessity for frequent renewals due to wear on any type of rubbing surfaces at the high speeds used in these bearing applications. Another important improvement in this respect, especially from the maintenance point of view is the use of "cartridge" type bearing construction which permits the removal, storage, and replacement of complete armatures without opening the bearing enclosures and the resultant risk of getting dirt into the bearings.

The a-c motor development also added greatly to our knowledge on such subjects as permissible limits in armature-field ampere-turn ratios, pole widths and shapes, pole-tip shapes and spacings, etc., all of which has contributed to a marked degree to the design of the d-c motor as well.

Noise reduction has become increasingly important; noises in electrical machines can be generally grouped into three classes—windage, magnetic, and bearing. As the result of careful study, air paths and air foil shaping of surfaces directing air flow are better understood and proper attention to these details has resulted in marked improvement. Intensive research has led to a better understanding of the sources of and remedies for magnetic noise. The use of skewed slots, or more recently, careful selection of number of slots in combination with proper pole shape and spacing, have both been found effective in reducing or eliminating magnetic noises. Bearing noise is of course largely a matter of proper control of bearing clearances and lubrication.

Figure 1. Motor for PCC car

The urge for smaller and lighter machines for a given rating forced the designers years ago to look for insulating materials which would stand operating temperatures beyond the limits of treated cotton insulation. This led to the use of mica and asbestos in various forms, and tremendous improvements have been made in the technique of manufacture and application of mica and asbestos insulation to railway motors. Unfortunately, both of these materials are natural products, found in only comparatively limited quantities in grades suitable for electrical insulation; like all natural products their characteristics are not uniform, and there is always the question of the ultimate exhaustion of available sources of supply. In addition, there are certain inherent limitations in these materials that at least so far have not been entirely overcome. For instance, both mica and asbestos are mechanically weak and therefore require, for practical manufacturing reasons, the use of certain carrier materials to add mechanical strength and stability during handling and application. Mica, being inherently a flaky material, is usually built up on a paper or silk tape carrier, and is somewhat difficult to apply satisfactorily to small conductors. Asbestos tapes are necessarily built up with cotton or silk cross threads to give mechanical strength, and there are certain definite limits in minimum thickness below which asbestos insulation cannot be obtained.

There has recently been developed a new material for high temperature insulation which affords very great promise—glass tape. This is a fabric type tape woven from threads of spun glass. It has most astonishing flexibility and strength, can be made in almost any required thickness down at least to 5 mils and of course has wonderful heat resisting and dielectric properties. Being a synthetic product its properties can be closely controlled, and the raw materials from which it is made are available in almost unlimited quantities. It is now beginning to be used in these types of high-speed railway motors, and it holds great promise as a means of still further improving designs.

A most important factor in the design and production of these small light-weight motors is the very large increase in limiting peripheral speeds of armatures and commutators as compared to previous practices. Here again the fundamental development work carried out on the a-c motor was directly applicable to these small d-c motors. It is not so very many years ago that 7,000 feet per minute on armatures and 5,000 on commutators were considered top limits. Now we are going up to 12,000 and 9,500, respectively. A number of factors are involved in this increase. Improved bearings and better understanding of bearing application, improved methods and materials for banding and wedging, better methods of dynamic balancing, and perhaps most important of all, very marked

advance in technique of design and building commutators have all contributed their share to the final results.

Armatures of the type used in these applications are balanced to within 20 inch-square ounces. The two planes at which corrective balance weights are applied are 11 inches apart, and the radius at which weights are applied is $4^1/_2$ inches, so it can be seen that the limiting weight tolerance is about two-fifths ounce.

Commutator improvements have been principally along the lines of better understanding of the forces acting on the bars at high speeds and temperatures, and the absolute necessity of maintaining a practically true cylindrical surface throughout the entire range of operating speeds and temperatures. We have come to realize that a very large percentage of our commutation and current collection problems are mechanical in nature, and to successfully meet them we must keep an intimate and continuous contact between the bars and the brush. When a real commutator expert speaks of a rough commutator he probably means one where the variation in radius from one bar to the next may be as great as four ten-thousandths of an inch.

A commutator is made up of a steel spider and V rings, mica bushing and V ring insulation, and copper and mica bars. All these materials have widely divergent mechanical and temperature characteristics, and their behavior under repeated cycles of speed, heating, and cooling is decidedly different. Successful solution of the problems involved requires the use of very high grade alloy steels for the bushings and V rings, extraordinarily careful selection and treatment of the copper and mica, and extremely close control of and tolerances in the entire process of building and seasoning. Seasoning has been found to be an absolutely essential final step in commutator manufacture. Each one is put through repeated cycles of spinning under heat, grinding and tightening until the entire structures acquires the necessary mechanical stability and the ability to "stay put" in service.

While the subject of commutation is under discussion another related important factor should be mentioned. Under all conditions, but particularly at the high speeds here involved, commutator and brush performance and life are very seriously affected by the presence of dirt in the ventilating air.

Earlier ventilated railway-type motors drew their incoming air directly from the space under the vehicle, with all the street dirt, wheel wash, and whatever else might be present. All this dirt and moisture is extremely bad for commutator and brush performance and life, and also for all the insulation in the machine. In the PCC car where partial or full skirting tends to carry the turbulent swirl of dirty air along under the car, it was felt that improved life and reduced maintenance of brushes, commutator, and coil insulation fully justified an effort to obtain relatively clean dry air for motor ventilation. Flat ducts

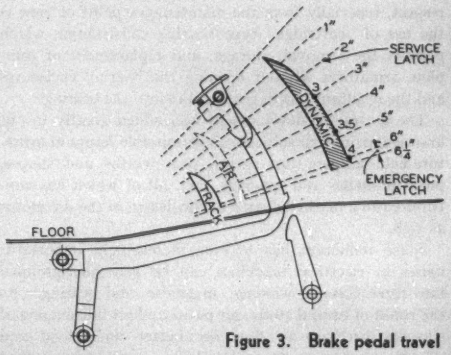

Figure 3. Brake pedal travel

are built into the body bolster just above the motors. Air is drawn into louvred openings at the outer ends of these ducts, outside the car skirt and practically at floor level. Flexible bellows connect these ducts to the motors.

The marked reductions finally achieved in weight and size of these types of motors sometimes lead purchasers to expect corresponding reductions in cost. From the very sketchy outline given above of some of the major problems of these designs and of their solutions, it must be clear that the reductions in weight and size have been possible only by the substitution of higher grade materials and very great increases in labor and tool cost per pound of material used. Price per pound may under some circumstances be a very useful index when applied to the same type of design and construction, but may be wholly misleading if radical differences in design and manufacturing processes are involved.

An important part of the research work carried on by the Presidents' Conference Committee was an investigation of the maximum rates of acceleration and braking

Figure 2. Accelerator for PCC car control

and the maximum changes of rate which could be comfortably tolerated by standing passengers. These research tests disclosed some very surprising results, and indicated that rates much beyond those previously considered possible were entirely acceptable, provided they were maintained sufficiently smoothly. Previously existing forms of control varied from 8 or 9 notches in standard *K* types to 14–18 in the then existing automatic types. These gave fairly comfortable accelerations at rates up to 2.5 or 3 miles per hour per second except for an occasional "bump" at transition, but were too rough at accelerations higher than this.

In an eight-notch *K* control, tractive effort increments of the order of 50 per cent of the previously existing value are quite common. In the earlier forms of automatic control this was reduced to about 20 per cent. In the present controls developed for PCC cars the percentage increment in tractive effort per notch is far too small to be perceptible even to standing passengers. Experience has indicated that after the number of notches is increased to about 22, further increases add nothing to passenger comfort, and the selection of number of notches becomes entirely a matter of the limitations of the type of contact device selected.

Actual street experience with the new cars has indicated quite definitely that it is possible for a street car to accelerate and brake as rapidly as a private automobile in the hands of an expert driver, and more rapidly than an average car in the hands of an average driver.

The success of the control equipments developed for these cars may be ascribed to the use of sufficiently large number of notches to eliminate jerks or surges in the acceleration, to the use of actuating means sufficiently sensitive and responsive to maintain smoothly the preselected rates of acceleration and braking, and particularly to means provided to ensure prompt and uniform response of the equipment in dynamic braking.

In one form of equipment the variable resistor device is called an "accelerator" (figure 2) and consists of a cylindrical assembly of resistors, tapped at 97 points, each tap connecting to a spring finger. Successive fingers are pressed into butt type contact with a copper bus by the action of a roller cam carried on an arm rotated by a 32-volt pilot motor through a small worm gear. A sensitive vibrating contact type of limit relay controls the direction and speed of the pilot motor, and thus controls the rate of change of resistance in the main motor circuits. The successive steps are so small in magnitude that individual increments of tractive effort are exceedingly small—far too small to be evident to passengers.

The limit relay setting is changed at the will of the operator by cams on both the brake and the master controllers which are in turn actuated by the foot pedals (or handles on cars arranged for hand instead of foot control) at the operator's position. Thus the one limit relay serves to regulate the automatic acceleration and the automatic dynamic brake, and also to control a function known as "spotting" which is further described below.

The brake controller is actuated from the operator's brake pedal and regulates all three forms of braking, dynamic, track, and air. It consists essentially of three parts mounted on a common shaft. A set of cam-actuated master-controller-type fingers establishes the proper control circuits for the change from motoring to braking. A brush arm rotating around a small fixed commutator regulates the series resistance in the track brake circuit. The third element is a self-lapping type of brake valve. (Figure 3.) The first three inches of pedal travel varies the rate of dynamic braking from a very low minimum rate up to about three miles per hour per second. At the same time the air brake valve is set for a pressure corresponding to the dynamic rate, but this air is blocked off from the brake cylinders by a "lockout" magnet valve which is energized as long as dynamic braking is in effect. When the speed is reduced to the point where dynamic brake begins to fade out, the lockout magnet is de-energized and permits air at the pressure already established at the self-lapping valve to flow to the brake cylinders without conscious action or further pedal manipulation on the part of the operator. The dynamic brake does not fade out suddenly, nor does the pressure in the brake cylinders build up instantly. There is an appreciable and almost equal time interval for both of these functions. As a result, the blend from dynamic to air braking is normally exceedingly smooth and free from any sense of sharp change.

Figure 4. One-hundred-twenty-five-horsepower trolley-coach motor

Pressure of the brake pedal from 3 inches to 6 inches travel superimposes a graduated amount of track braking on top of the dynamic or air brake already obtained, so that rates higher than three to three and one-half miles per hour per second are obtained partially from dynamic and partially from track braking, with air coming in automatically as the dynamic fades out at low speeds.

Depression of the brake pedal to the "full" or emergency positions cuts out the lockout magnet and gives full application of dynamic, track, and air brakes, with automatic application of sand to the rails.

In the other form of equipment available, the variable resistor element consists of a special form of resistors with about 150 taps connected to the bars of a fixed commutator. A brush arm is rotated around this commutator by an air engine, and an ingenious arrangement of transfer

contactors permits the use of this variable element twice during acceleration and four times during braking by switching fixed blocks of resistance in or out of the circuit in series with the variable element. In this equipment also a sensitive type of limit relay controls the rate of change of resistance both in motoring and in braking.

In earlier forms of dynamic braking some difficulty was experienced in getting prompt and uniform response at various speeds at the time of application of braking. During dynamic braking the motors are acting as series generators, with voltage varying over a wide range from maximum to minimum speed. In order to quickly establish a given rate of braking the value of resistance in circuit at the time of brake application should therefore be definitely related to speed. For lack of a better name, the means of accomplishing this has been called "spotting" and it is incorporated in both forms of equipment, although somewhat different methods of accomplishing it are used in the two schemes. In general, spotting establishes the correct value of resistance in the circuit, so that either braking or reapplication of power is promptly and smoothly established following a period of coasting.

Early experience with certain of the experimental cars indicated the desirability of more than one form of storage braking, that is, independent of power supply. It was felt that the high speeds of which the new cars were to be capable could not be used effectively unless the operator was fully confident of his abilty to obtain good braking even with bad rail and with an interrupted power supply. This led to the development of a battery excited track shoe. The presence of a battery on the car for this purpose naturally led to the use of the battery for control energy, so that in effect three forms of storage brake are available—in other words even with power off the line or the trolley off the wire, dynamic, track, and air brakes would all function.

The use of a battery required some means of charging. This led to the use of a motor generator set, which was then made to perform the additional functions of driving the air compressor and the 1,250-cubic-feet-minute blower used in conjunction with car heating and ventilation, as described in other papers on this program.

It is evident that the electrical equipment as well as other features of the PCC car incorporate many features radically different from previous practices in the streetcar field, and while troubles have been encountered, none of them may be said to be of a fundamental nature, and all of them have been or are being overcome. At least two of the largest operators have expressed themselves as having experienced less trouble with these cars than any lot of new cars they ever placed in service.

Trolley-Coach Equipment

The modern trolley coach may be said to have had its beginning with the Salt Lake installation in 1928. Its growth has been phenomenal—relatively slow at first but now increasingly rapid. There are now in service or on order 1,270 trolley coaches in the United States in addition to "all-service" type vehicles which operate either as trolley coaches or gas electrics.

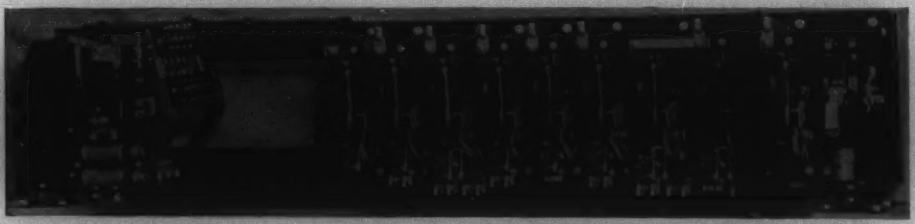

Figure 5. Trolley-coach control panel

The earliest motors used were 50 horsepower, but with increasing weights of coaches and increasing severity of service 65-horsepower motors weighing 785 pounds each became standard—two on 40 passenger coaches and one on 30 passenger.

Control equipments of the variable automatic type have become pretty well standardized for two motor equipments and a simpler nonautomatic type for the 30 passenger single motor coach since these are generally used for lighter service in smaller cities where high rates of acceleration are not so important.

Within the last two years there has been an increasing demand for lighter and simpler equipment for 40-passenger coaches (36 to 44). Development of a suitable single-bowl axle to handle the output of a single motor of sufficient size to give adequate performance on coaches weighing from 17,500 to 20,000 pounds has brought about the development of such motors. There are now in service or on order in the United States 447 trolley coaches using 125-horsepower single-motor equipments.

(Figure 4.) This motor rates 125 horsepower one hour rating and weighs 1,100 pounds, a weight of only 8.8 pounds per horsepower. As in the case of the PCC car motor, this result is partly due to the use of high-temperature insulation and improved designs of roller bearings, but principally to developments in design and manufacture of high-speed armatures and commutators. This

motor is particularly noteworthy in this respect as it must necessarily be designed for 600 volts while the PCC motor is wound for 300 volts, two in series on 600.

Another feature of this equipment which makes the motor design even more remarkable is the unusually wide spread between full field and short field curves. There has been a growing conviction for some time in the minds of certain operators that the period of constant-current acceleration is too short, i. e., that acceleration should be carried to higher speed before striking the short field motor curve. The new single-motor 125-horsepower equipment is supplied in two forms, one with a relatively small amount of field shunting, in a single step, and one with three steps of field shunting with a final shunting of over 50 per cent. With the latter arrangement constant-current acceleration is carried up to a speed of 25 miles per hour as compared to 17 miles per hour with the single point shunting. This feature not only permits better schedules but is of great value in passing slower moving vehicles in the street. It also gives higher balancing speeds; while these higher balancing speeds may not often be reached on level runs, the entire speed curve is raised and on hilly routes higher speeds may be maintained on grades.

The single-motor equipment, because of the absence of series-parallel control, has a slightly higher power consumption than the two-motor equipment. In many applications it has been found that the increase in power cost is more than offset by the lower weight and cost, greater simplicity, and reduced maintenance and inspection cost of the equipment. In some cases, where unit cost of power is particularly high or for other reasons, the two-motor equipment may be preferred. Each case must be considered on its own merits and the final selection made by the purchaser on the basis of his own conditions.

(Figure 5.) The development of the single-motor equipment has brought about marked improvement in control equipments. These are now available in forms in which all the equipment except current collectors, motor, and resistor is mounted on a single panel, adapted for either side or rear pocket mounting, and completely wired at the factory. This greatly simplifies installation by the coach builder, and inspection and maintenance by the operator.

It has been found that because of the torque cushioning effect of the tires, a smaller number of notches than on cars gives equally smooth accelerations. The new equipments have 13 or 15 notches including one or three steps of field shunting. Automatic acceleration is universally used on 40 passenger coaches. Marked improvement has been made in simplification of the equipment by improved means of obtaining automatic progression.

In one form of control now available, the progression is entirely by means of electrical interlocking and a sensitive-type limit relay. This has been made possible by the use of "split" operating coils having two sections—a "pull in" winding and a "holding" winding. This scheme greatly reduces the number of interlocks required, and along with the development of a more sensitive current relay removes the obstacles which originally made it necessary to depart from progression interlocking on small capacity equipments—i. e., our inability to put enough interlock fingers on the relatively small contactors required for this size equipment, and the lack of a sufficiently quick response relay.

Another form of control recently developed for single-motor coaches obtains its automatic progression by means of winding up a spring which drives a camshaft through an electromechanical escapement mechanism between the spring and the camshaft.

Some of the features worked out in connection with the PCC car are finding their place in trolley-coach practice as well. In some cases, accelerating-resistor losses are being used for coach heating; in others, definite provision is being made to bring cleaner drier ventilating air to the motors.

The trolley coach is meeting with enthusiastic public response, and is proving itself a vehicle of very great value in that field between the heavy trunk-line route served by street cars and the lighter-service routes served by gas busses.

Gas-and Diesel-Electric Bus Equipment

Another interesting field for the application of electric propulsion equipment is the drive or transmission for gas and Diesel busses. It has been found that mechanical transmissions for large size busses in frequent-stop service are not altogether satisfactory. Frequent acceleration up to the limit of engine capacities imposes severe strains and heavy wear on transmission, clutch, and rear end, and the mechanical labor, time lost, and roughness incident to frequent to gear shifting are serious disadvantages from the standpoint of operator and passenger.

The development of the transit-type bus with rear compartment or under-floor-mounted engines has tended to make the mechanical transmission problems more difficult, and the introduction of Diesel-type engines with their less favorable speed flexibility has also tended to emphasize the advantages of electric drive.

Fundamentally and internal-combustion-type engine performs best as a constant-speed, constant-load prime mover. In urban transit vehicles the power and speed requirements are continually varying over a wide range. The problem presented to the electrical designer is to attempt to reconcile these conflicting characteristics of prime mover and vehicle.

At starting the demand is for high tractive efforts at low speed, which electrically means high current at low voltage; as the speed of the bus increases the current demand gradually falls off and the voltage rises, until at the balancing or free running condition, a low current at high voltage is required. It has been found that these requirements can best be met with a shunt generator with a moderately drooping voltage characteristic, so that the combined motor and generator speed-tractive effort curve approximates a rectangular hyperbola—thus giving very nearly constant horsepower and constant speed loading to the engine. When starting from standstill with the engine idling, a small amount of battery excitation is applied to the shunt field to assist the generator in quickly picking up its load as the engine accelerates. This is cut off by a voltage re-

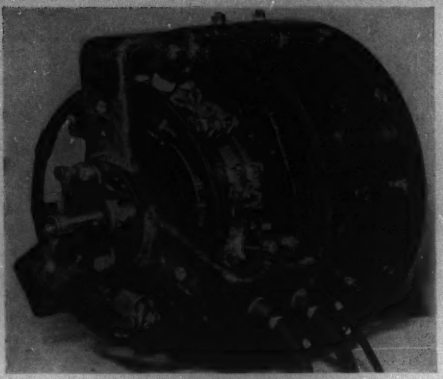

Figure 6. Gas-electric-bus generator

lay, as over excitation of the field for too long a period tends to hold down the engine speed. The prompt pickup charteristic assists in giving electric drive one of its major advantages over a gear shift. With electric drive the engine speed is quickly raised from idling to full speed where it is maintained—thus giving full engine speed and horsepower throughout the acceleration period. This is in marked contrast to a shifting gear mechanical transmission, where each full start consists of three or four successive engine accelerations from idling to full speed, interrupted twice or three times by periods of declutching, shifting, and reclutching so that the average engine speed and power during acceleration is materially below full value, with resultant loss in over-all rate of acceleration.

As bus sizes and weights increase and as service conditions become more severe as a result of increased traffic congestion and the application of busses to heavier-service routes, the tendency is toward larger, more powerful engines. The electrical designer is constantly being called on to provide equipment for larger engine capacities, but of course, is also under continually increasing pressure to produce smaller, lighter, and cheaper motors and generators. Everything that has been said earlier in this paper about the advances in design and manufacturing procedure applies to the machines for electric drive of busses with special emphasis, because electric drive is fundamentally heavier and more expensive than the mechanical drive which it replaces.

In this connection it should be pointed out that, contrary to beliefs apparently held in some quarters, electric drive can never put any more horsepower at the rear wheels than it gets out of the engine. Too often in discussing the performance to be expected from a given bus with electric drive, standard engine curves, taken under conditions vastly different from those which will exist with the equipment as installed in the bus are regarded as showing the engine output under operating conditions. It is important in predicting the performance of busses that account be taken of such items as auxiliaries—fans, battery charging generators, air compressors, etc., and that proper reduction in power delivered to the generator be made. The particular carburetor type and jets with which the equipment is to be used should also be used in making dynamometer tests.

Generators, motors, and control equipment are available for a range of 110 to 180 horsepower in gross engine output, for both single-reduction and double-reduction axles. Figures 6 and 7 show typical generators and motors for gas-or-oil-electric-drive applications.

A particularly interesting form of gas-electric bus is the "all-service" vehicle, developed and widely used on the Public Service Co-ordinated Transport in New Jersey. This vehicle is capable of operation either as a gas-electric or as a trolley coach. As usually built it has a single generator and two motors. The motors are connected in parallel for operation from the generator and in series for operation from the 600-volt trolleys. This vehicle has obvious advantages of extreme flexibility—it may operate over parts of its route where either local ordinances or low traffic density preclude the use of overhead wire, while retaining the advantages of trolley coach operation over heavily traveled sections of the route. It is also available for chartered or other service on unwired routes.

The only essential difference in its electrical equipment from a straight gas-electric is in the requirement of operation from 600-volt trolley, and the provision of current collectors and suitable changeover devices from engine to trolley operation.

We have attempted in this review to give a picture of the recent advances in the design and manufacture of electrical

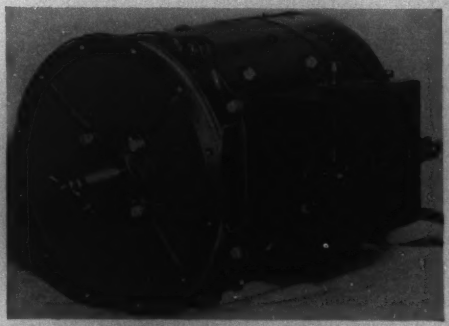

Figure 7. Gas-electric-bus motor

equipment for these public urban transit vehicles—not that these results are final—but rather as a survey of what has been done, and an indication of the direction in which further progress can be expected.

Cities exist and will probably continue to grow—public transportation is an absolutely essential service and must continue to expand and its methods must progress. We confidently expect that electric propulsion will continue to occupy a vitally important place in this field.

Application of Modern Electric Vehicles to Urban Transportation

By C. M. DAVIS
ASSOCIATE AIEE

THE URBAN transportation problem involves the movement of large numbers of city dwellers to and from work, school, or the shopping districts. These movements are frequently concentrated into a few hours in the morning and evening, and are handled largely through city streets, or, in the larger cities, on subway or elevated lines. The corporations handling this business, commonly called "mass transportation," operate under franchises from local authorities. These franchises usually specify minimum service over specified routes.

Transportation by private automobile or in public taxi cabs involves a large number of vehicles for a relatively small number of passengers transported. It would be impossible for our larger cities to function without the organized transportation systems of rapid transit, street railways, or busses. Not only would the cost of daily transportation be greatly increased for the great majority of riders, but the cities themselves would have to be rebuilt, if highways were to be provided of adequate capacity to handle, in small capacity vehicles, the present users of urban transportation systems.

What, then, is the ideal transportation system for our cities? It is one that will move the traveling public at the highest schedule speed consistent with safety; with a minimum of waiting time; with reasonable comfort; with the least interference with other traffic; and at the lowest cost, including fixed charges on the capital investment, consistent with the foregoing requirements.

Urban transportation is handled at the present time by four classes of service — rapid transit lines operating on private rights of way, over or under city streets; surface street railways; trolley coach lines; and gas busses. Each has a proper field which is not only the most logical, but the most economical from the community standpoint, though existing systems do not in every case justify this assumption.

In the small city, where the available traffic on any individual route is limited to 100 or 200 passengers per hour in the direction of maximum movements, which can be handled by small vehicles on 15- or 20-minute headways, the gas bus may be the logical type to use, since it involves a lower investment, and in some respects, lower operating costs than other forms of transit. Busses seating 20 passengers and carrying ten standees, on 15-minute headways, can carry away from a given area 120 passengers per hour, and the installation cost per mile of route will be very small compared to other types of service. With the cheaper types of gas busses of this size, a route giving 15-minute service, may be equipped including garage facilities, for $3,000 to $4,000 per mile. When pioneering into new territory in small or medium sized cities, this is probably the logical equipment to use.

However, routes in many cities are operated with such vehicles on long headways, where a more attractive service might substantially increase riding, and amply justify larger and more attractive units, more frequent headways, or both.

Larger gas busses, seating 30, on 15-minute headways, could handle 180 passengers per hour, and would require an investment of $8,000 to $9,000 per mile of route, including spares and garage. On the same headway, 40 passenger units can carry 240 passengers per hour, and will have an installation cost of approximately $12,000 per route mile.

But at about this point of traffic density, the trolley coach comes into the economic picture. These vehicles have a body and chassis similar to those of the highest grade gas busses, but instead of the engine, clutch, transmission, radiator, gas tank, and battery, they use electric motors and control and take their power from a pair of trolley wires, through poles sufficiently long to permit the vehicle to move 12 to 14 feet to either side of the wires. The simplicity and long life of this type of equipment effects lower maintenance and depreciation as compared with gas busses. Electric power is usually cheaper than gasoline. The overload capacity of its motors, an unlimited supply of power available, and the smoothness of its application make it possible to accelerate at rates far in excess of the most powerfully engined gas bus, and to make faster schedule speeds in frequent stop service.

However, the installation cost of a trackless trolley system is much greater than one operated by gas busses. Its use involves a pole line carrying four trolley wires that may cost $5,000 to $10,000 per route mile to erect, and an investment in substation facilities of from 30 to 40 kw for each vehicle operated, costing $1,500 to $2,000. On 15-minute headways, with 30 passenger vehicles, a trolley-coach system will have an installation cost per route mile about $6,000 higher than a gas-bus system, and with 40 passenger vehicles on five-minute headways, the difference in investment would be around $12,000 per route mile in favor of the gas bus.

But the economic life of the trolley coach should be appreciably longer than that of the gas bus, so its depreciation rate would be less. The line work may be assumed at five per cent or less annual depreciation, and the substation not more than four per cent. Even on this basis, the gas bus system will have an advantage in annual fixed charges for interest and depreciation of from $400 to $700 per route mile. This, however, amounts to but 0.6 cent to 0.8 cent per vehicle mile operated.

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On the other hand, operating records from companies using both types of vehicles indicate that, in the heavier classes of urban service, trolley coaches will save enough in equipment maintenance, power, and garage accounts as compared to gas busses in similar service, to much more than offset their higher fixed charges, and that they will attract more traffic by giving a smoother, quieter, more comfortable, and faster ride to users of the service.

Cost of service, therefore, including fixed charges, will usually be lower for a trolley-coach system if vehicles seating 30 passengers or more are to be used on headways of 15 minutes or less. This is true for new routes. It is even more apparent when an existing street-railway route is changed over to rubber-tired vehicles, for the substation and much of the distribution system is already paid for and installed, so the excess cost of the trolley-coach system over gas busses will be much less than was indicated in preceding calculations, and the relative costs of service are more certain to favor the electrically propelled coach.

As an alternative, where physical, political, or financial factors dictate the use of large-capacity motor busses instead of trolley coaches, the former may be equipped with electric drive, and obtain advantages in faster acceleration, and hence higher schedule speed, greater quietness and smoothness of operation, and a reduction in engine fumes. The electric drive consists of a generator directly connected to the engine, delivering power to a motor geared to the driving axle. Its use eliminates the clutch and gear transmission of the usual mechanical drive, and results in lower maintenance cost. It greatly reduces physical effort on the part of the driver, and provides a faster and more comfortable ride for the passengers.

Diesel engines with mechanical drive, in frequent stop bus service, have developed many mechanical difficulties that are minimized or eliminated when electric drive is installed. In fact, it appears that the successful employment of Diesel engines in passenger busses in urban service is conditioned upon the use of electric transmission. A number of such Diesel-electric busses have been put into operation in the past year, and they are showing such substantial reductions in fuel costs, as compared to gas busses, that it is safe to say many more installations will be made.

One large transportation company has introduced a distinctly new type of rubber tired vehicle using electric drive. This is the so-called "all-service vehicle," nearly 500 of which are in service, and which is primarily a trolley coach, but equipped with gas-electric drive for routes where no trolley wires are available, for use on detours, or for excursion work on Sundays or holidays when not all of the fleet are needed on trolley routes. When beneath the wires, the two motors used on these vehicles are operated in series; when power comes from the engine, the two are placed in parallel across a low voltage generator. They are normally operated as trolley coaches, but under certain conditions have greater flexibility than the straight electric coach.

The standard type of 40-passenger gas busses, so far built in this country, can carry in rush hours, with reasonable comfort, not over 70 passengers, and probably cannot operate at less than 40 second headways without interfering with one another. This means a street capacity of 90 units per hour, carrying 6,300 people in the direction of maximum traffic.

Trolley coaches, seating 40, where they are confined to city streets, are built to larger dimensions and wider aisles, and can carry loads 20 per cent to 25 per cent heavier, so on the same headways they might move 7,600-7,800 passengers per hour.

Under such conditions, the investment required would be about $245,000 per route mile for the gas busses, and $275,000 per mile for the trolley-coach system. From an economic standpoint, a street-railway system would be preferable, despite the expense of track construction, which, in paved streets, may cost $100,000 per mile.

A modern street car, seating 60, can readily handle 120 rush-hour passengers, so 53 cars per hour could carry away the 6,300 assumed for the busses, and 65 per hour equal the capacity of 90 trolley coaches. The rail system would have a lower investment in vehicles, shop facilities, line and substation than the trolley coach, but the cost of track would bring the total investment required up to $320,000, 30 per cent above that of the gas bus, and 15 per cent higher than the trolley-coach system. Due to differences in depreciation rates, the fixed charges on the three systems would be approximately equal. Operating costs on the rail system would be very much lower, due to the smaller number of vehicles, even though their cost per car mile would be appreciably higher. The total cost of service for the rail system, under these conditions, may be assumed as $22,000 less per route mile per year than the trolley coach system, and $35,000 less than the gas bus system, besides causing less street congestion for other vehicles using the street.

As the density of traffic decreases, the advantage of the large-capacity rail car becomes less apparent, and to handle rush-hour traffic requiring 2-minute service with trolley coaches, or 3-minute service with rail cars, the costs of service are equal. Again, it might be pointed out that where tracks are already installed and in good condition, the economic dividing line between the rail and trackless service would be in a much lighter traffic field.

If the street railway be used to its maximum capacity, operating on the 40-second headways assumed for the busses, it could handle 10,800 people per hour in the direction of maximum movement, or three parallel streets with rail lines could handle as much as five parallel-bus, or four trolley-coach routes, leaving 33 per cent to 67 per cent more street space available for other traffic. The relative cost of service would be even more favorable to the rail than in the example to which we previously referred, despite an installation cost for the street railway of nearly $500,000 per route mile.

The foregoing discussion is based on the use of the most modern type of large capacity street cars, equipped to operate at schedule speeds as high as even the trolley coach can perform. Such cars have been developed by the industry within the past three years and are operating in Brooklyn, Chicago, Washington, Baltimore, Pitts-

burgh, Los Angeles, and other cities. As compared to the slow and antiquated equipment that constitutes the bulk of the rolling stock in most cities today, any type of new vehicle, even gas busses, may be justified on economic grounds and earning power, but we believe that in many cases where gas busses have replaced rail service, it would have been better economics to use modern street cars or trolley coaches.

Now we come to the only system that can handle the volume of traffic of our largest cities, the rapid transit systems operating on private rights of way. These are expensive to build, and their carrying charges are enormous, but so is their carrying capacity. The latest system of this type, the four-track municipal subways built and equipped by the New York Board of Transportation, is arranged to handle 11-car trains, each having a capacity of 3,080 passengers, on 90-second headways, or 123,000 passengers per hour on the express tracks alone. Including the local tracks, the total one-way capacity is probably in excess of 180,000 per hour. The older Interborough lines, using smaller cars and shorter trains, now regularly carry 100,000 to 120,000 per hour at the peaks. Even the latter figure equals the capacity of 11 street railway routes, or of 19 streets filled with busses, and the municipal installation may, at no distant date, carry 50 per cent more. Its cost for construction and equipment will probably average $12,000,000 per route mile, but high as this appears at first glance, it is very low in terms of community benefits compared to many other expenditures intended to expedite the movement of passenger traffic.

Chicago spent $22,000,000 a mile to build a two-level river front marginal way, the well-known Wacker Drive, which has an effective capacity of 2,500 automobiles per hour in each direction, or perhaps 5,000 passengers. Fairmont Parkway in Philadelphia, Michigan Avenue in Chicago, and the Sixth Avenue Extension in New York, roads costing from $14,000,000 to $19,000,000 a mile, are other examples of city expenditures, of greater magnitude than subway costs, to provide faster movement for a relatively small number of people.

The New Jersey State Highway from the Holland Tunnel to Newark Airport cost nearly $6,000,000 per mile to build. Its capacity for auto riders is about 4,500 per hour in each direction, and if one lane in each direction were given over to busses, it would still carry less than 10,000 people per hour, so 12 to 18 such highways would have to be provided to equal the subway usefulness.

Many street widening projects have been undertaken in New York, Brooklyn, Detroit, Boston, and Pittsburgh to relieve vehicular congestion and to expedite traffic, that averaged $6,000,000 per mile, including condemnation of property, and even so, the movement of vehicles through them is less rapid than that of the subway trains.

No form of surface transportation in metropolitan areas can approximate the speed of rapid transit trains. No possible expenditures can be made that will permit the movement of an equal number of people in small, individual vehicles, autos, or busses as fast, or as economically as can the subway.

As compared to its nearest competitor in efficient handling of the heaviest traffic, the street railway using the most advanced equipment, the subway costs twice as much to build, as surface lines of an equal hourly capacity. If we neglect the cost of the street in which the rails are laid. On the face of things, it would appear that difference in first cost penalizes the users of the subway in high fixed charges. This is not a fact, however. Of the $12,000,000 referred to as the subway cost, only $3,000,000 or 25 per cent, went for cars, shops, tracks, power distribution system, signals, lights, etc., on which depreciation must be set up, and the other $9,000,000 went into real estate and construction, in other words, into nondepreciable items. Moreover, the depreciation rate on the track and on the cars is lower than for surface equipment, and calculations indicate that if both systems were financed by 50-year bonds carrying a sinking fund that would amortize the principal in that period, and adequate depreciation set up for both, the fixed charges on 11 surface lines would almost exactly equal that of the subway, which would be $850,000 per route mile per year.

The operating cost of the rapid-transit system per car mile is less than that of the surface line, and very much less per passenger handled. While it is impossible for either the privately operated or municipal subways to show an adequate return on the investment on a five-cent fare, and some of the surface rail and bus systems appear to be doing so, the conditions are not comparable.

The average rider on the surface travels not over two or three miles. The average subway ride is at least four times as long. If the surface lines had to carry their passengers the same distances as do the subway trains, instead of picking up a series of overlapping loads, their revenue per car mile or bus mile would decrease in inverse ratio to the longer ride and would fail to equal their out-of-pocket operating expense, whereas the subways operate for between 50 per cent and 60 per cent of their passenger revenue.

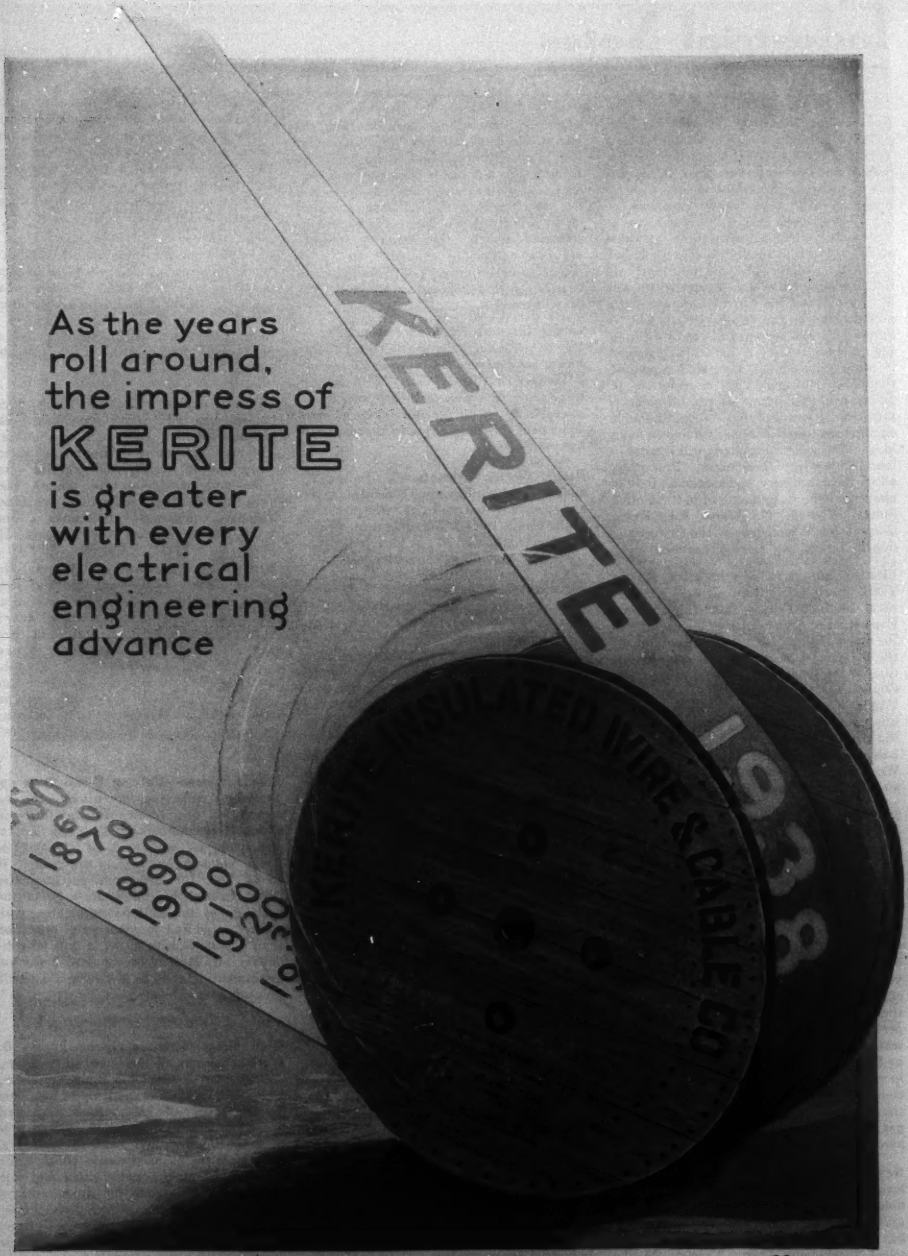
Aside from questions of operating economics, it would disrupt the business life of the community if those using public transport had to take two and one half times as long to get to work and return, which is about the ratio of schedule speeds on the surface to that of the subway.

Density of rush-hour traffic to and from the business areas is the final measuring stick that should govern the type of transportation service in every community. It is generally agreed that for our largest cities rapid-transit lines, subway or elevated, are an absolute necessity to the proper functioning of the community life. In addition, there is every economic justification for retaining and re-equipping a very considerable amount of surface rail transportation in these cities, and the rail service should be supplemented with trolley coaches and gas busses.

In the larger cities which are functioning without rapid transit facilities, it would appear that the modern rail car is still the most suitable vehicle for the heaviest traffic routes, but many existing rail lines should be changed to trolley coach operation. In many smaller communities, even up to perhaps 500,000 population, it

is probably good engineering economics to gradually discard the rails and supplant them with trolley coaches and gas busses.

In all cities large enough to require mass transportation, it appears certain that electrically propelled vehicles, whether rail cars or trolley coaches, should be used for the great bulk of the service, having the ability to provide a faster, safer, more comfortable, and more economical form of passenger transportation than any other form now used in public service.



THE KERITE INSULATED WIRE & CABLE COMPANY INC

NEW YORK CHICAGO SAN FRANCISCO

Industrial Notes

New Power Plant for Oil Fields.—The J. G. White Engineering Corporation of New York has been awarded a contract for the design and construction of a 20,000-kw power plant for the Venezuelan Oil Concessions, Ltd., a subsidiary company of the Royal Dutch-Shell group operating in Venezuela. The company now operates an extensive field on the eastern shores of Lake Maracaibo. The oil wells in this field are pumped by gas engines which will be replaced by electric motors when the power plant is completed. Steam will be generated by either natural gas or oil from the adjacent fields. A 15,000-foot channel is being dredged for a suitable supply of condensing water. The distribution of power from the plant to the oil wells is provided by means of the 33,000-volt double circuit steel tower transmission line 35 miles long. The generating plant will consist of four 5000-kw turbo-generators. Practically all of the machinery and materials for the plant are being manufactured in the United States. The J. G. White Engineering Corporation is in charge of the engineering design, purchasing and construction.

Electric Exhibits for San Francisco Fair.—Three more firms have signed contracts with the 1939 Golden Gate International Exposition at San Francisco for exhibits in the huge Hall of Electricity, according to the division of electricity and communication for the World's Fair of the West. The General Cable Corporation, the Gordon E. Wilkins Company, and the Bowie Switch Company, are the latest signers. Among the large exhibitors are the Bell Telephone Laboratories, General Electric Company, Westinghouse Electric & Mfg. Company and the Pacific Gas & Electric Company.

Record Sales of Lamps in 1937.—A preliminary estimate indicates that more than a half billion large incandescent lamps were sold in the United States during 1937 according to a review of the electrical industry prepared by Guy Bartlett of the General Electric Company. A total of 955,000,000 is indicated for both large and miniature lamps—515,000,000 large and 440,000,000 miniature. Each of the totals is the highest yet attained. Perfection of a new high-efficiency tungsten filament, which increases the light output of incandescent lamps 10 per cent without using additional current, was one of the outstanding developments in the field of lighting during 1937. This increase in efficiency results from greater concentration of the lamp filament. With the new filament there is less cooling by the gas in the lamp and more light for a given amount of current results.

New Decibel Meter.—A rectifier-type power level indicator and voltmeter in which a new circuit network provides improved uniformity of operating characteristics, has been announced by the Weston Electrical Instrument Corp., Newark, N. J. Known as the model 695 type 11, the unit has a constant internal resistance of 20,000 ohms, both into the instrument from the line under test, and from the instrument into the network toward the line. As furnished in a portable case, the unit consists essentially of a rectifier type indicating instrument with a $2^1/_2$-inch scale mounted on a Bakelite panel, together with range-changing switch, the required internal network, a blocking condenser and jack-type output terminals. Two 4-foot leads complete with test prods are supplied with each instrument.

Larger Quarters for Tech Laboratories.—Due to increasing business the Tech Laboratories have moved to a new factory at 7 Lincoln St., Jersey City, N. J., where three times the space of their former plant is available. With the installation of new equipment their former production capacity has been doubled.

Pacific Electric Appointment.—Judson E. Holland has been appointed general manager and assistant to executive vice-president of the Pacific Electric Manufacturing Corp., San Francisco, Cal. F. A. M. Jones succeeds Mr. Holland as superintendent.

Aerovox Appointment.—George H. L. Norman has been appointed chief engineer of Aerovox Canada Limited, Hamilton, Ont. Mr. Norman has been with the Aerovox Corporation in Brooklyn, N. Y., since 1935 and has designed much of the test equipment now used for wet and dry electrolytics, and for paper, oil and other condensers.

General Electric Appointment.—Charles E. Wilson, of Bridgeport, Conn., vice-president in charge of General Electric's appliance and merchandise department since 1930, has been elected executive vice-president of the company, a new position. Mr. Wilson has been with the General Electric Company and one of its constituent companies, Sprague Electric, since 1899, and has served in practically every function of the business and in many capacities.

Trade Literature

Current Transformers.—Bulletin 57, 4 pp. Describes bushing type current transformers of unusually high accuracy for metering purposes. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Cal.

Capacitors.—Catalog 2-X, 16 pp. Describes a complete range of transmitting capacitors. Full specifications and costs are included. Solar Manufacturing Corp., 599 Broadway, New York, N. Y.

Industrial Thermometers.—Catalog 1125 B, 24 pp. Describes a comprehensive line of industrial thermometers and their applications. Hygrometers, U gages and mercurial barometers are also listed. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

Recording Instruments.—Bulletin No. 496. Describes various improvements recently made in Bristol recording voltmeters and ammeters. Sample chart records and photographs of the new instrument models, showing the compact and simple operating mechanism are included. The Bristol Co., Waterbury, Conn.

Fixed Condensers.—Bulletin. Describes 3 types of fixed condensers with unusual operating characteristics. These small capacitors, manufactured under the trade name of Erie Ceramicons, consist of a ceramic dielectric with coated plates of pure silver. Erie Resistor Corp., 646 W. 12th St., Erie, Pa.

Motors.—Bulletin 1410. Describes vertical hollow and solid shaft polyphase, ball bearings, squirrel cage induction motors. Although developed primarily for direct connection to vertical-shaft turbine, propeller and centrifugal type pumps, they have found wide application on other industrial equipment. Fairbanks, Morse & Co., 900 So. Wabash Ave., Chicago, Ill.

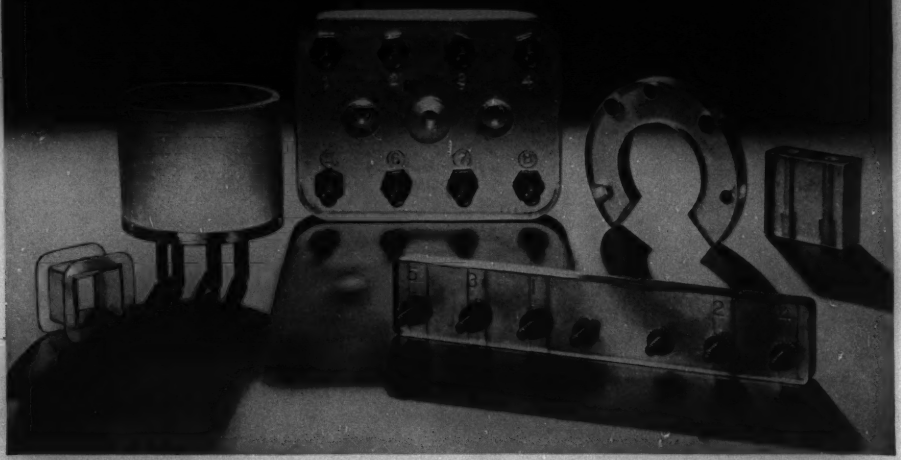
Wire Alloys.—Catalog C-1, 36 pp. Describes alloys used in wire, rod and strip form. In addition to listing the description, application, and price per pound of alloys, it contains wire data, the range of uses, current temperature characteristics of wire, resistance and feet per pound. In the electrical field, where high temperatures and resistance to oxidation are most important, data on the forms of alloys to be used are set forth. Alloy Metal Wire Co., Inc., Prospect Park, Pa.

Potentiometers.—Catalog E-50B(2), 8 pp. Describes deflection potentiometers and accessories, of interest to laboratories in which large numbers of d-c deflection instruments are calibrated or checked, or where lamp-efficiency tests are made. It shows how the deflection potentiometer brings to such measurements most of the accuracy of the null potentiometer, with greater speed and convenience of operation than is possible with either a null potentiometer, or a laboratory standard deflection instrument. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Ohio Brass Founder Dies.—Frank B. Black, chairman of the board of directors, and founder of The Ohio Brass Company, Mansfield, Ohio, died suddenly at his home on December 19. Mr. Black organized The Ohio Brass Company in 1888 to produce brass valves and saddlery hardware. Soon after the business was established the company began the manufacture and sale of overhead equipment for street railways and mines and later added porcelain insulators for high tension transmission lines. Under his guidance the company grew steadily until today plants are operated in Mansfield and Barberton, Ohio, and Niagara Falls, Canada.

Announcing...

BAKELITE POLYSTYRENE LOW-LOSS MATERIAL



Advantageous applications of Bakelite XMS-10023 Material include: coil forms, tube bases, terminal blocks, spacing washers, connector blocks.

AFTER exhaustive research and development in its laboratories, Bakelite Corporation now contributes to electrical science and industry a superior thermo-plastic material for low-loss purposes.

Possessing the extraordinary properties in a molded plastic, of a power factor of less than .0002 at frequencies of 60 to 1,000,000 cycles, and a dielectric constant of 2.60 at the same frequencies, this new Bakelite Polystyrene molding material offers marked advantages for many electrical products and equipment parts. Its dielectric strength is more than 500 volts per mil; its resistivity, over 10^8 megohm centimeters; and its arc-resistance, 240 to 250 seconds.

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BAKELITE CORPORATION OF CANADA, LIMITED, 163 Dufferin Street, Toronto, Canada *West Coast:* Electrical Specialty Co., Inc., 316 Eleventh Street, San Francisco, Cal.

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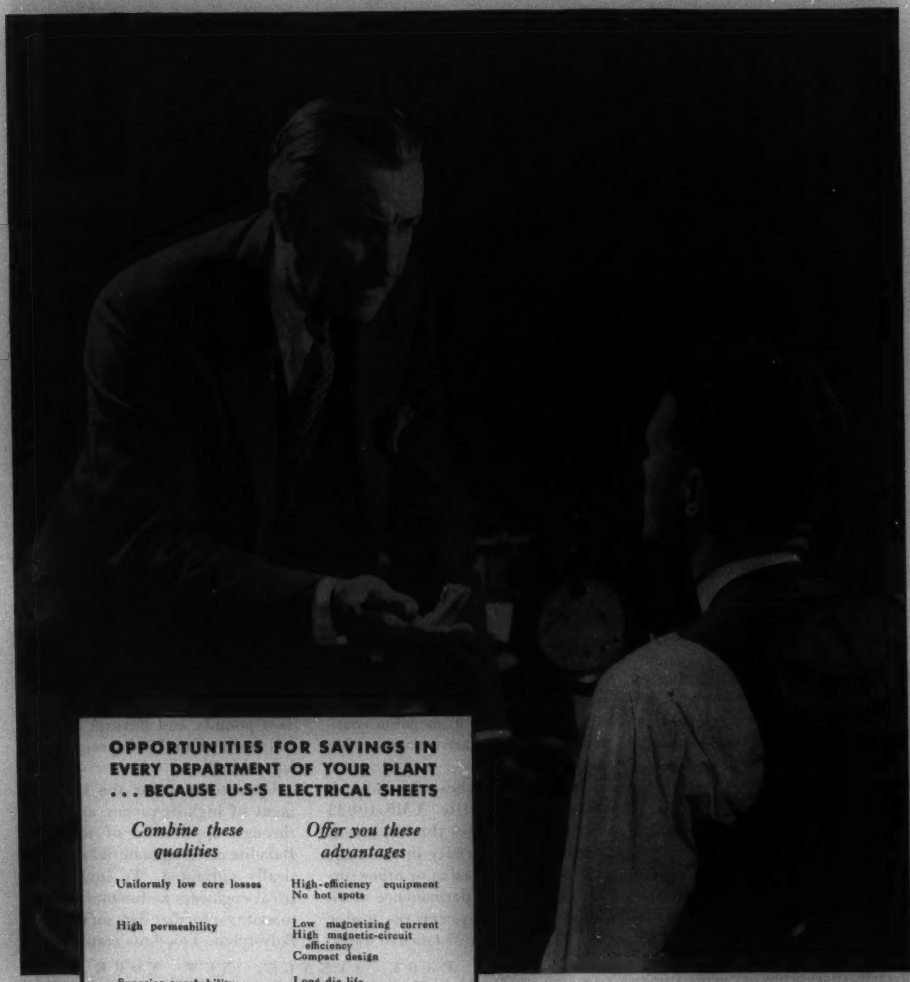

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Flat and true to gauge	High space factor Compact design Low production costs
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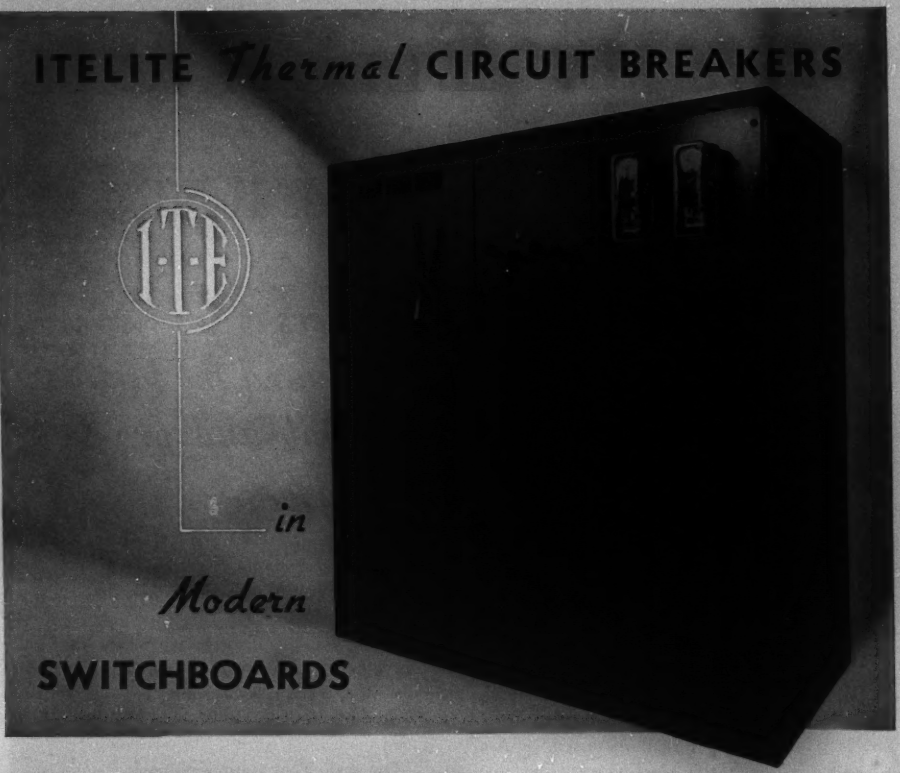
UNITED STATES STEEL

ITELITE *Thermal* CIRCUIT BREAKERS



in

Modern

SWITCHBOARDS

THE use of ITELITE Thermal CIRCUIT BREAKERS in modern switchboards, protecting lighting and power circuits, is increasing.

The increase is the result of ITELITE performance coupled with economy both in first cost and in service.

Illustrated above is a typical switchboard for a modernized industrial plant. The main circuit breaker, upper left, is a manually-operated air breaker. Submains are protected by 600-ampere-frame thermal breakers shown with extended handles. Individual feeders both lighting and power are protected by smaller frame units. Time delay in the main breaker is adjustable so that any ITELITE will open dangerous overloads on its circuit without affecting other circuits in the system.

All ITELITES have high interrupting capacity. Standard frames, extremely compact, offer various ratings by a simple change of trip units. Carrying capacities range from 10 to 600 amperes up to 600 volts a-c and to 250 volts d-c.

225-ampere frame ITELITE above, with Bakelite cover removed.

Two black-finished steel enclosures for surface mounting, shown open and closed, at left.

Representatives in Principal Cities

I·T·E CIRCUIT BREAKER CO., PHILADELPHIA, PA.

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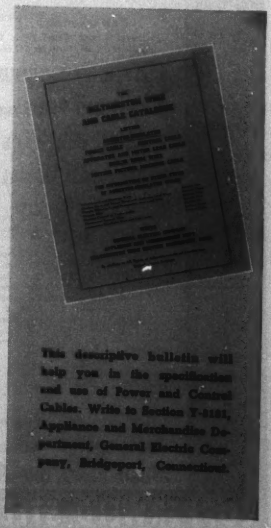
PURIFIED ASBESTOS INSULATION GUARDS AGAINST BREAKDOWNS

Certainly you want wire and cable insulated to meet every day requirements. But—you want more than that. Dependable power circuits demand an insulation that gives extraordinary service—even when conditions are most severe. **And that means Deltabeston!**

All Deltabeston Conductors are insulated with **Purified, Felted** Asbestos. By an exclusive process, a greater percentage of organic materials is removed than in any other commercial asbestos. Felted to the conductor, the insulation does not crack or break.

Deltabeston Power Cable and Apparatus Control Cable will aid in your plans for profit. Insulated with Purified Asbestos, they are built for long years of service. Heat and moisture do not impair their dependability.

For greater insulation resistance—higher dielectric strength, specify Deltabeston. It's a logical — and profitable — step in plant operation. Deltabeston Wires and Cables are distributed by General Electric Merchandise Distributors and Graybar Electric Company.



This descriptive bulletin will help you in the specification and use of Power and Control Cables. Write to Section T-8181, Appliance and Merchandise Department, General Electric Company, Bridgeport, Connecticut.

GENERAL ELECTRIC

DELTABESTON WIRE AND CABLE

APPLIANCE AND MERCHANDISE DEPARTMENT, GENERAL ELECTRIC COMPANY, BRIDGEPORT, CONNECTICUT

But are you using **ALL** *these*

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COPPERWELD PRODUCTS?

- **STRAND** — 3, 7, and 19 wire for: Guy Strand, Span Wire, Messenger Strand. Also Cable Rings.
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- **RAILROAD SIGNAL BONDS** — Jumpers & Track Circuit Connectors.
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In addition to the Copperweld products YOU are now using, there are others that can provide an equally profitable answer to your rusting problems. Check this list and if there are any of the items on which you would like more information, ask the Copperweld representative to tell you about them at the time of his next visit. Also, mail this coupon for detailed information.

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COPPERWELD STEEL COMPANY

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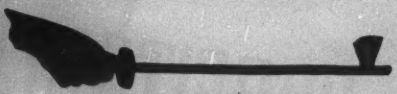
COPPER BRONZE COPPERWELD RODS, WIRE, AND STRAND

THE STATISCOPE



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Designed to give positive indication of the presence of potential, 2,000 volts and up.

Its sensitivity is independent of external capacities. Made of Hard Rubber rod, 24 inches long. There is 12 inches of solid rubber between the handle guard and internal metal parts.

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Adapted for underground cables.

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"MADE by American Steel & Wire Company" means a lot to buyers of electrical wires and cables. It means absolute reliability based upon years of satisfactory service from thousands of installations.

Amerseal Non-metallic Parkway Cables are designed for direct burial in earth, without external protection. In these cables a jacket of tough vulcanized rubber, covered with a heavy layer of asphalted jute, protects the insulated conductors from mechanical injury and from action of moisture, earth acids and alkalis. This unique construction gives full protection to the cables, yet you will find them light in weight, flexible, easy to handle and extremely economical.

Our Steel-Taped Parkway Cables have rubber insulated conductors protected by a lead sheath and by one or more layers of metallic armor. Use our Armorlokt or flat steel-taped metallic cables wherever added mechanical protection is necessary. For complete information, send for our new Parkway Cable catalogue.

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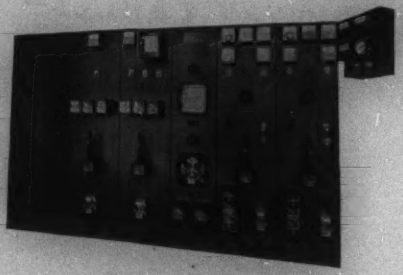

*Such as Indicating and Recording Instruments; Air and Oil Circuit Breakers; Rotary Switches; Regulators; Transformers; Relays; Disconnects

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Employment Bulletin

Engineering Societies Employment Service

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

B.S.E.E., '30, M.Sc.EE, '32, married, 28; exper n hydro-elec des, appraisal, statistical, personnel. Desires pos in personnel, purchasing, sales or exec dept of engg firm. Location immaterial. E-151.

AIRCRAFT ELEC ENGR, B.S.E.E., 1926; 7 yrs exper supervising devpmt, des and instal aircraft elec and auxiliary pwr eqpt. Desires pos offering opportunity for advancement. E-154.

E.E., draftsman, 27, married; 7 yrs with large pwr co, planning underground, overhead transm and distr systems, estimating, draftg, ltg plans for apartment houses, offices; interested research; available immed. E-145.

E.E., 31, interested in future; location optional; 4½ yrs in the merchant marine as electrician. Past 3 yrs worked as chief electrician on motor vessels. E-152.

ELEC. DISTR. ENGR, 37, exec ability; 17 yrs util, indus, consulting exper includes des, constr, oprn, valuation. Desires affiliation with util, indus or consultant where ability and co-operative initiative are requisites. E-142.

ENGG MGR, 20 yrs exper com field and mgmt sound pictures U.S. and abroad. Exper includes supervision of engg devpmt and planning, instal and oprn, commercial engg and tech consulting. E-158.

E.E., B.S., Co-operative course, minored in acctg; single, 35; 8 yrs Westinghouse as tester, draftsman, motor engr; 2 yrs city planning. Desires any of following: Business, engg, city planning. E-143.

E.E., B.S., 1937, single, 22. Desires pos in elec. field. Location immaterial. Has had exper with util. E-144.

GRAD E.E., 1936, Newark Col of Engg, interested in mgmt and prod end of indus. Exper: Prod engr; instructor. Location, Metropolitan NY Area. E-147.

SENIOR E.E. STUDENT, 22, single; 3 yrs. elec instal and maintenance exper with contractor. Desires pos offering future. NY vicinity preferred. E-148.

E.E., B.S., NYU Evening, 1937; 26, 2 yrs asst to chief engr in indus co; 4 yrs sales and service with business machine co. Employed. Desires pos with growing concern. E-149.

B.S.E.E., Jan, '36. Married, 25; 2 yrs structural des transm lines and supervision draftg room for mfg co. Some engg advertising and radio exper. Location immaterial. Employed, desires better opportunity. E-150.

GRAD E.E., B.S., '36, M.S. '37, Case Sch of Applied Science, single. Exper in elec appliance mfg concern. Desires tech pos in elec indus. Available immed, location immaterial. E-153.

E.E., B.S., Rutgers, 1935; 2 yrs tel exper, one yr turbine and pump exper, one yr air conditioning maintenance. Desires pos in maintenance, testg or sales with elec mfg co. E-155.

E.E., B. S., Marquette Univ, 1936; 24, married, dependable, adaptable. One and a half yrs mech. exper, inspection, testg and home study. Desires junior engg pos mech or elec. E-157.

E.E., married, 30; 2 yrs G.E. test, 3 yrs pwr plant oprn, 3 yrs indus and util evaluation; registered prof engr; employed. Desires advancement. Location, East. E-146.

E.E., B.S., 1930, single, 31. One yr Westinghouse grad student training course; 2½ yrs teaching physics; 4 yrs CCC Officer. Desires draftg, des exper, teaching or any pos engg field. E-159, 3711-C-7-San Francisco.

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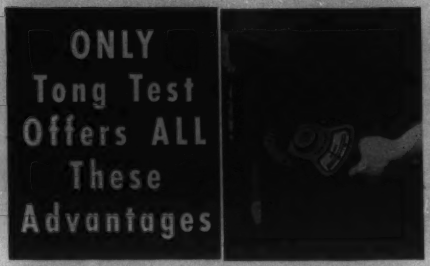

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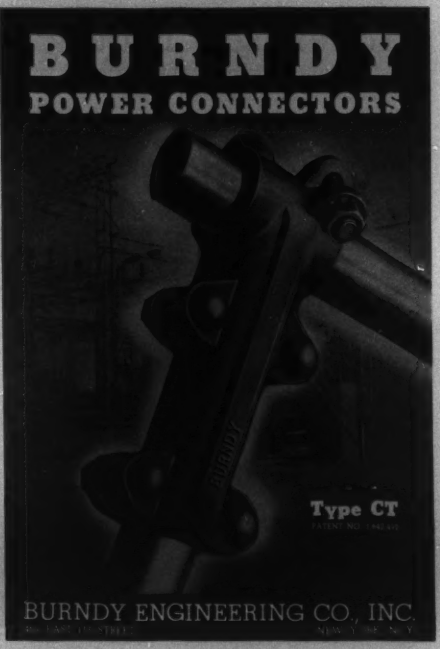

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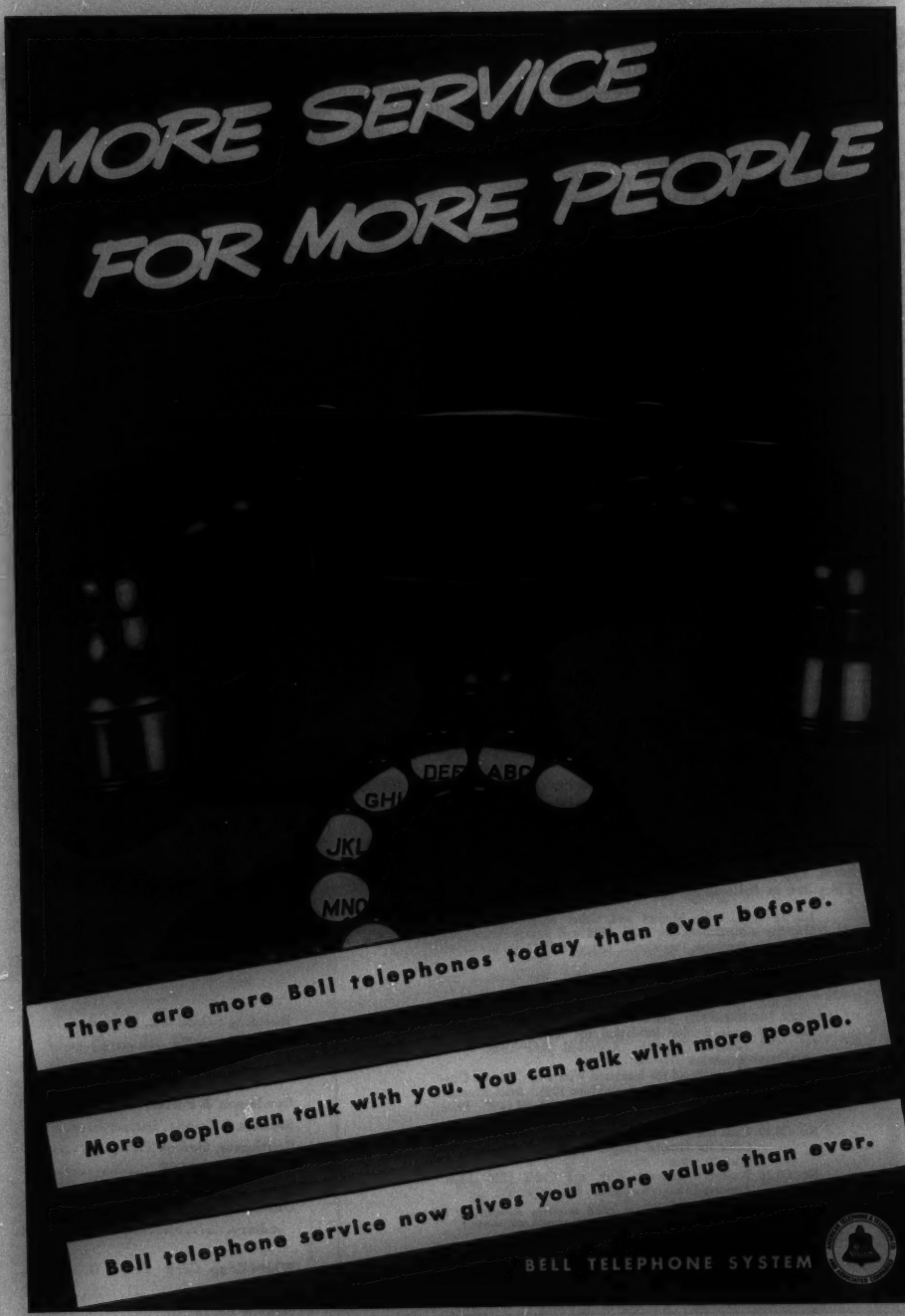
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